HABITAT USE OF A POPULATION OF PRIMARILY FOREST-DWELLING BROWN TEAL, PĀTEKE (Anas chlorotis)

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By

Katie A. Sheridan

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Acknowledgements

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Abstract

Prior to human settlement, pāteke were one of the most prolific species of waterfowl in New Zealand, inhabiting widely varied habitats ranging coastal marshes to dry beech forests. Upon arrival of humans and non-native mammalian predators to New Zealand, the pāteke population dwindled rapidly, reaching its low of 1,000 birds, circa 2000. Remnant populations became isolated within two locations at Great Barrier Island and Northland. It is within these greatly-modified coastal habitats that pāteke conservation efforts (i.e., predator control, habitat restoration, release of captive-bred birds) are currently focused. This study evaluates roosting and foraging patterns and home range attributes of the population of pāteke residing with the fenced and primarily-forested Zealandia – Karori Wildlife Sanctuary with the goal of determining suitability of forested sanctuaries as future release sites for the brown teal. Seven transmitters were fitted to birds known to utilize forested habitat ("bush pāteke") and three transmitters were fitted to birds known to roost along lake edges ("lake pāteke") to provide a basis for comparison. Birds were tracked during the day and occasionally night, and motion-sensing video cameras were used to supplement the pool of night data for the foraging analysis. Using the 95% MCP method, lake pāteke home range (mean = 1.84 ha) was significantly smaller than that of bush pāteke (mean = 20.22 ha) (P = 0.017). Difference in 50% MCP core area size was not significant (P = 0.383). Using the 95% KUD method, lake pāteke home range (mean = 3.52 ha) was significantly smaller than that of bush pāteke (mean = 24.71 ha) (P = 0.017). Difference in 50% KUD core area size was not significant (P = 0.118). Home range overlap was most common at the flock site. Genetic diversity is a significant concern for this population, with 51.4% of known nests being the direct product of inbreeding. Regarding roosting behavior, the 50% KUD core roost areas for lake pāteke (mean =

0.597 ha) were not significantly smaller than that of bush pāteke (mean = 3.261 ha) (P = 0.117). However, the 50% KUD core roost areas of pāteke who maintained core roost areas exclusively adjacent standing water were significantly smaller than that of pāteke with core roost areas in the bush (P = 0.032). Mean roost distances to the nearest lake for lake pāteke (mean = 3 meters) were significantly shorter than that of bush pāteke (mean = 643 meters) (P = 0.017). No discernable trend in roost preference based on season was observed. Difference in linear foraging range between lake pāteke (mean = 944 or 866 meters) and bush pāteke (mean = 2218 or 2082 meters) was large, but did not meet the threshold for statistical significance (P = 0.183). Lake edge foraging proportion for lake pāteke (mean = 56.1% or 59.0%) was significantly greater than that of bush pāteke (mean = 5.3% or 5.7%) (P = 0.017). Cameras positioned at the mouth of the flock site stream and 270 meters further upstream recorded the highest foraging density at 10 birds. Greatest foraging frequency was recorded by cameras along the upper and lower lake edges, near the flock site stream mouth and along the southern half of the faultline stream. The greatest argument facing the use of forested release sites for pāteke is that these sites offer habitat that is either unsuitable or of marginal quality. Findings suggest that pāteke have retained the behavioral and physiological plasticity required to utilize forested habitat and that primarily-forested habitats provide suitable release sites for pāteke, provided several conditions are met: intensive and ongoing predator control must be implemented; a large flock site of suitable composition must be available; supplemental feeders should be made available for at least two months post-release, and; the site must be of adequate size to accommodate a minimum of 50 pairs of pāteke. Given that bush pāteke had significantly larger home ranges and foraging ranges than their lakeside counterparts, a forested facility able to accommodate 50

pairs would need to be much larger than its coastal counterpart. Where feasible, predator control outside and adjacent to release sites may assist in creating a large enough release site to accommodate a sustainable population size.

1 Introduction

Prior to human settlement, pāteke were one of the most prolific species of waterfowl in New Zealand (Buller, 1888, as cited in Hayes & Williams, 1982). Based on fossil evidence, teal inhabited a wide range of habitats, including low-lying coastal marshes, wet podocarp forests, sedge-dominated lakes and marshes and dry beech forests nearly 700 meters above sea level (Worthy, 2002). Pāteke diet has also shown to be highly varied, with birds observed to feed upon 78 different taxa of flora and fauna (Moore et al., 2006). Recently, stable isotope analysis has shown that some teal living in pre-human New Zealand were forest floor omnivores (Holdaway, Williams & Hawke, 2013).

Upon human settlement, brown teal numbers dwindled rapidly, with the agents of decline being predation by introduced mammals, destruction of habitat, hunting and disease (Dumbell, 1986). At its most critical point, the pāteke population fell to just 1,000 individuals (O'Connor, Maloney & Pierce, 2007). Through conservation efforts, numbers have increased to between 2,000 – 2,500 birds (DOC, n.d.). The majority of these birds are found in three main populations located on Great Barrier Island (n = 900), Northland (n = 400) and Coromandel (n = 300), with the remaining birds located in captive breeding facilities and on predator-free offshore islands and mainland "islands", where they have been reintroduced for their safety (DOC, n.d.).

Presently, brown teal conservation efforts are concentrated within the locations of the three aforementioned remaining population strongholds, all of which consist of coastal wetlands abutted by low-lying pastoral fields (O'Connor et al., 2007). It is within this narrow range of habitats that the vast majority of field-based brown teal studies have been conducted. However, as Holdaway et al. (2013) indicated, it is not

necessarily best practice to restrict future conservation efforts for a species on what is known of small and declining populations, particularly since we know that their current range is an extremely truncated representation of their natural range.

This study evaluates roosting and foraging patterns and home range attributes of the population of pāteke residing with the fenced and primarily-forested Zealandia – Karori Wildlife Sanctuary with the goal of determining suitability of forested sanctuaries as future release sites for the brown teal.

1.1 Pāteke, an endangered, endemic, nocturnal duck

1.1.1 Taxonomy and morphology

Brown teal fall under the following taxonomic classification:

Class: Aves

Order: Anseriformes

Family: Anatidae

Genus: *Anas*

Species: A. *chlorotis*

Vernacular names: brown teal (English); pāteke (Maori)

Brown teal, or pāteke, are a fairly small duck, measuring approximately 48 centimeters in length. On average, females weigh 500 grams and males weigh 600 grams (Heather & Robertson, 2005). Both sexes have deep brown plumage with lighter brown mottling and have a small, distinct white ring around each eye. Pāteke exhibit sexual dimorphism during breeding season, at which time males develop a

glossy green sheen on their heads and occasionally a white neck ring, striations along their side flanking with white patches on either side of their rear flanking and a chestnut-colored chest. When not in breeding plumage, males and females are very difficult to distinguish. Males produce a soft wheezing sound as well as whistles, while females produce a louder, raspy quack.

1.1.2   Behavior and ecology

Brown teal are elusive and cryptic and thus, are well-suited to inhabiting environments with dense understory. Their present-day population strongholds in the northern North Island consist of coastal and estuarine wetlands adjoined by pastoral fields (Weller, 1974). These semi-aquatic environments provide substantial emergent grasses and forbs within which the pāteke roost and forage.

Brown teal typically congregate at traditional flock sites from December to March (Williams & Dumbell, 1996). Often, juveniles and singles will remain at the flock site for a longer period, or for the entire year. Flock sites are used by pāteke to form and/or strengthen pair bonds. Between March and May, pairs begin to leave the flock site in search of a breeding territory. Clutches are typically laid between June and October (Heather & Robertson, 2000). However, brown teal are known to breed year-round, particularly in captive facilities or environments where food is readily available (Reid & Roderick, 1973).

1.2   History of pāteke, pre-human to present day

Since its physical separation from Gondwana nearly 85 million years ago, New Zealand has been geographically isolated and void of any ground-dwelling mammals (Worthy & Holdaway, 2002). The absence of land mammals has had a profound impact on avian evolution. Not only did the absence of land mammals leave many

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ecological niches vacant, it allowed for other organisms to evolve free from the selective pressures of mammalian predation. Brown teal, or pāteke (*Anas chlorotis*), are a prime example of these unique selective forces and thus, occupy an ecological niche which is described as "*almost unique amongst the world's waterfowl*" (Williams & Dumbell, 1996).

Among the most notable characteristics of many native New Zealand avifauna, is their inability to fly. Evolution in the absence of land predators greatly reduced the need for flight. Because flight is so energetically taxing, many species of birds including takahē, kākāpō, Auckland Island teal and Campbell Island teal to name a few, are believed to have stopped flying to conserve energy (Olson, 1973; Feduccia, 1980; McNab, 1988; Diamond, 1991, as cited in McNab, 1994). Over millions of years, they lost even the ability to fly, with their wings becoming smaller and weaker (McNab, 1994). Unlike their two closest relatives (the Auckland Island and Campbell Island teal), brown teal are still capable of flight, although they are very reluctant to do so (Evans, 2015a). In the presence of perceived danger, pāteke tend to hide or hold perfectly still (Evans, 2010; Heather Robertson, 2005, as cited in Rickett, 2010). While this defense mechanism likely worked well against the pāteke's former top predator, the Haast eagle, it works very poorly against mammalian predators, who locate prey primarily by scent (Conover, 2007).

Introduction of the first mammalian predator to New Zealand occurred as early as 2000 years ago, when it is believed the kiore rat was introduced by Pacific explorers (King, 1990). With the arrival of the Maori in New Zealand approximately 900 years ago came the introduction of domestic dogs (Holdaway, 1996). While the presence of these two introduced predators likely had some effect on the pāteke, it would seem

that the pāteke were able to maintain a healthy and substantial population. Some of the earliest firsthand accounts of pāteke were recorded between 1840 – 1850 (Buller, 1882; Pycroft, 1898; Hamilton, 1885; Guthrie-Smith, 1895, as cited in Hayes & Williams, 1982). While these records are limited in number and occasionally contradictory, it is safe to say that pāteke were abundant and widely dispersed throughout the North and South Island at that time, although more so throughout the North Island (Hayes & Williams, 1982) (Figure 1-1).
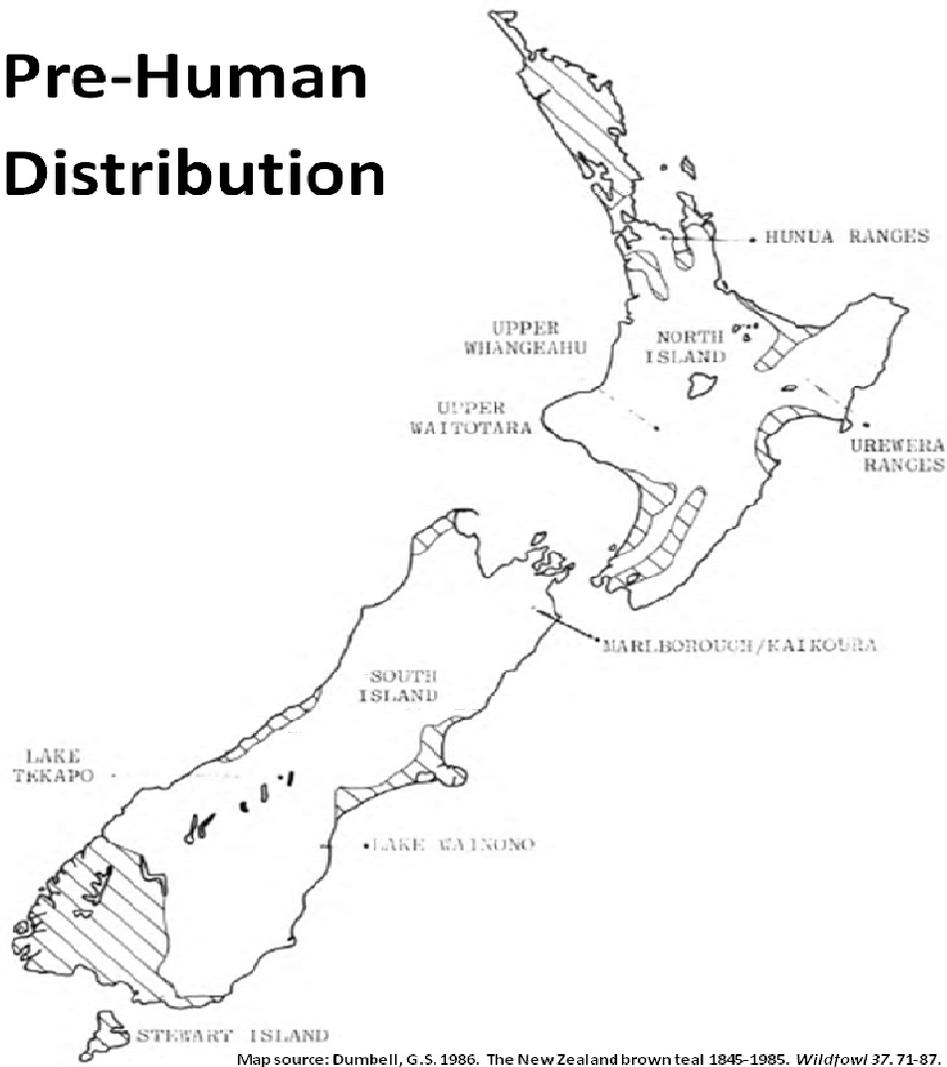
Figure 1-1. Pre-human pāteke distribution, shown as shaded areas (Dumbell, 1986).

Throughout the late 1700s and early 1800s, large numbers of European settlers arrived in ships, which carried three additional species of rodent (King, 1990). Numerous other species, including several mustelids, were deliberately introduced either as livestock, for hunting, or eventually as agents of biocontrol (Parkes & Murphy, 2003). The introduction of these mammalian predators in conjunction with widespread drainage of wetlands for farm development, clearing of forests, and pressures from hunting and disease all took a toll on the brown teal population (Hayes & Williams, 1982; Dumbell, 1986). Brown teal numbers were noted to be dwindling as early as 1882 in the South Island (Potts, 1882, as cited in Hayes & Williams, 1982). The overall brown teal population lingered throughout most parts of the country, until the 1920s to 1930s, when the overall population experienced a dramatic decline (Hayes & Williams, 1982).

By 1986, Dumbell noted that the brown teal was New Zealand's rarest anatid and that their overall population likely hovered near 1,500 wild birds (Dumbell, 1986). At its most critical point in the early 2000s, only 1,000 individuals remained in the wild (O'Connor et al., 2007). Through years of intensive conservation efforts, which will be discussed in the following section, the brown teal population has begun to rebound. It has most-recently been estimated that between 2,000 and 2,500 brown teal now exist in the wild (DOC, n.d.). The majority of these birds are located within three remaining strongholds, all of which are located within the north-easternmost portion of the North Island (DOC, n.d.) (Figure 1-2).
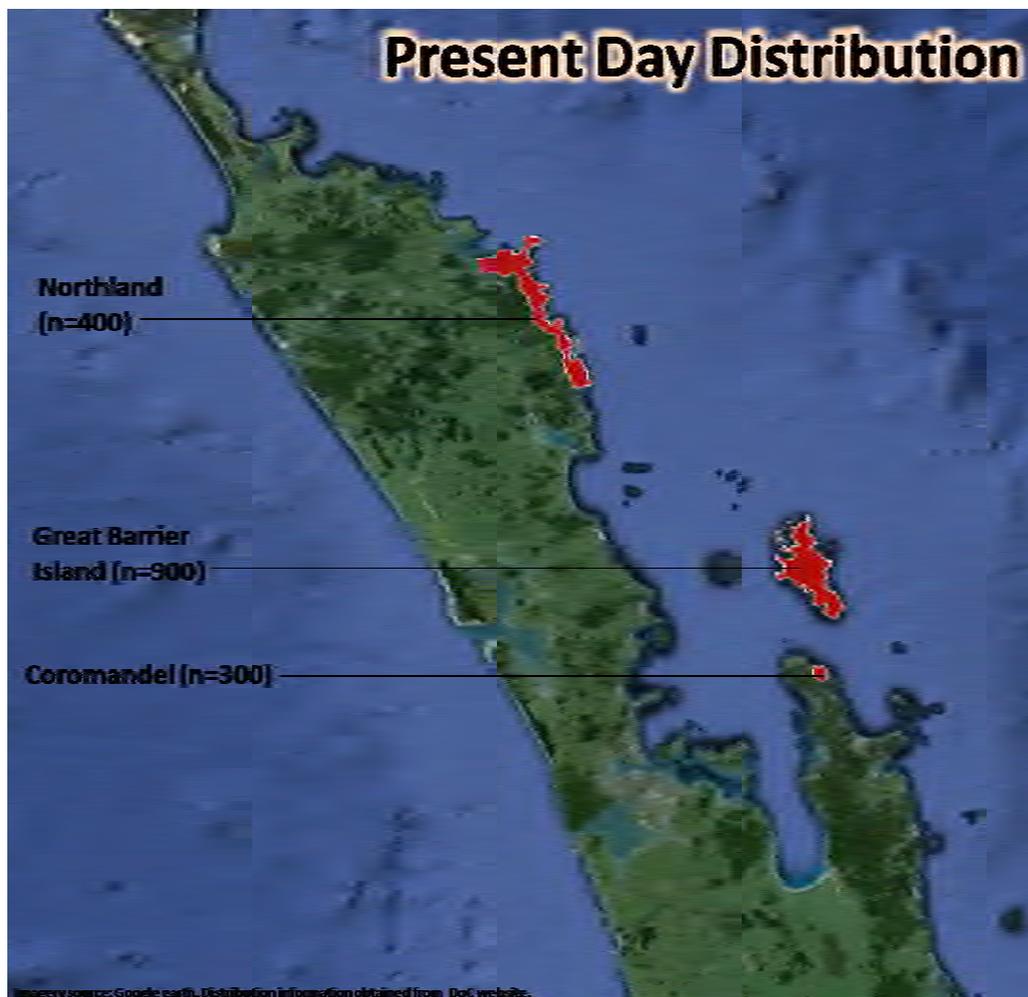
Figure 1-2. Present day pāteke distribution, showing locations of the three remaining strongholds.

1.3   Pāteke conservation efforts

Perhaps the first initiative towards the preservation of pāteke was in 1921, when pāteke became legally protected from hunting (Williams, 1985, as cited in Dumbell 1986). Unfortunately, hunting did remain a factor in the decline of brown teal, although it was not likely the primary cause. The next effort in pāteke conservation came in the form of captive breeding. Although a handful of private New Zealand residents were known to hold captive brown teal, the first documented successful

captive breeding of pāteke occurred in 1960 (Fisher et al., 1969, as cited in Dumbell, 2000). From 1964 to 1974, brown teal were removed from wild populations, which were rife with predators, and placed in the security of captive breeding programs by the Wildlife Service and Mt. Bruce Native Bird Reserve (Dumbell, 2000; Hayes, 2014). These operations remained somewhat limited, however, until the establishment of Ducks Unlimited NZ in 1974 (Dumbell, 2000).

Beginning in 1974, Ducks Unlimited launched "Operation Pāteke" and formally created the brown teal captive breeding program (Hayes, n.d.). The three main objectives of "Operation Pāteke" included a.) the establishment of 50 breeding pairs in captivity, b.) to breed over 1,000 individuals in captivity and release them into suitable environments, and c.) to save pāteke from extinction (Hayes, n.d.). In the first year the operation was implemented (1976), 19 pāteke were reared in captivity, followed by 18 pāteke in 1977, 29 in 1978 and 45 in 1979 (Hayes, n.d.). Numbers of captive-bred teal continued to increase dramatically from that point forward (Hayes, n.d.). In an attempt to avoid genetic bottlenecking as well as to bolster numbers within the captive breeding scheme, pāteke were captured from the largest remaining wild population (Great Barrier Island) in 1960-1972, 1974, 1976 and 1987, amongst other years, and were used to top up the reserves of pāteke already within captive breeding facilities (Hayes & Williams, 1982; Hayes, n.d.).

Recommendations were made as early as 1885 for the use of offshore islands as havens for the reintroduction of brown teal (Martin, 1885, as cited in Dumbell, 1986). The first pāteke release occurred in 1968, wherein nine captive-reared and one wild pāteke collected from Great Barrier Island were released onto Kapiti Island Nature Reserve (Williams, 1969). With breeding confirmed within four months of their

release, the release was initially deemed a success (Williams, 1969). Numerous other releases were carried out in subsequent years throughout the North Island. Between 1977 and 1983, 320 captive-bred teal were released in Manawatu (Hayes & Dumbell, 1989). Around this time, pāteke were also released in groups in the Wairarapa, Taranaki, Hawke's Bay, Bay of Plenty and Nelson areas (Roderick, 1973; Williams, 1978; Pirani, 1981; Mills & Williams, 1984, as cited in Dumbell, 1986). Unfortunately, for nearly all of these releases, years after release, pāteke were noted to have dispersed and disappeared (Dumbell, 1986).

In 1994, the brown teal was identified on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species as "Endangered" (IUCN, 2015). By this point, it was becoming evident to conservationists that, although the captive breeding program had likely saved the species from extinction, captive breeding and release into locations within both their former and current ranges was not sufficient in and of itself to reverse their rapid decline towards extinction. The same year of the IUCN status determination, the NZ Department of Conservation (DOC) requested that "Operation Pāteke" be scaled back, so that DOC could concentrate its resources on preparing and maintaining suitable release locations as well as putting more focus on monitoring the condition of newly-released brown teal populations (Dumbell, 2000).

In 1996, DOC published their first Brown Teal Recovery Plan, a document that provided a detailed synopsis of the current status of pāteke and created a framework in which groups (including Ducks Unlimited, the newly-formed Pāteke Recovery Group, DOC. Wildlife Service and others) could work together to save the pāteke from extinction (Williams & Dumbell, 1996). The fundamental goals of this 10-year plan included maintaining the major remaining population strongholds of pāteke on

Great Barrier Island and Northland, establishing new island and mainland populations, identifying the genetic status of the Fiordland brown teal population, and broadening public support of these conservation efforts (Williams & Dumbell, 1996). Of particular relevance to this thesis, this Recovery Plan, as well as the updated Brown Teal Recovery Plan (2007), places emphasis on the importance of intensified predator control and habitat suitability in locations where pāteke are planned to be released (Williams & Dumbell, 1996; O'Connor et al., 2007).

In conjunction with these plans, intensive predator control efforts and/or habitat/wetlands restoration efforts were undertaken throughout islands and mainland "island" preserves where brown teal populations were already present, as well as at locations where they planned to be introduced in the future. Efforts towards predator control and wetlands creation proved to be well worth it. Pāteke released on Tiritiri Matangi Island in 1987 and 1990 and on Moturoa Island in 1995 and 1996 have remained on the islands and continue to sustain themselves to an extent (Dumbell, 2000). In some cases, such as on Tiritiri, the small facility size (220 ha) prevents pāteke from sustaining a viable population (Parker, 2013). However, pāteke have the potential to intersperse amongst nearby populations on Moturoa Island and Tawharanui (Parker, 2013). Similarly, releases to Cape Kidnappers and Ocean Beach Wildlife Preserve (CKOBWP), Tawharanui, and Tuhua Island have proven successful (A. Booth *et al*. *in litt*., 2012, as cited in IUCN, 2015).

The continued success of Ducks Unlimited's captive breeding program in combination with the more systematic, holistic and targeted approach set forth in DOC's Brown Teal Recovery Plans, pāteke have been making a strong comeback. In 2008, DOC changed the national threat classification of pāteke from "Nationally

Endangered" to "Recovering" (DOC, n.d.). On October 1, 2015, the IUCN downgraded the status of pāteke from "Endangered" to "Near Threatened" and noted the current population trend as "increasing", signifying the continued success of conservation efforts for the species (IUCN, 2015).

That being said, much work is still to be done for pāteke recovery. Currently, the four fundamental approaches identified by DOC for pāteke recovery efforts include predator control, habitat restoration, captive breeding/release, and increasing public awareness (DOC, n.d.). Recently, Holdaway et al. (2013) have suggested increased exploration and efforts in trialing fenced, forested wildlife sanctuaries for the release of brown teal. They have shown through the review of fossil records as well as a comparison of diet variation through stable isotope analysis of historic and present pāteke bones, that pāteke were at one time well-suited to live in forests (Holdaway et al., 2013). The question therein remains as to whether, after many generations removed from this forested life, present-day pāteke retain the behavioral plasticity required for survival in the bush.

1.4   Pāteke at Zealandia – the study site

1.4.1   Site description

Zealandia, formerly named the Karori Wildlife Sanctuary, is the world's first fully-fenced urban ecosanctuary, situated within a primarily-forested valley approximately 1.5 kilometers west of the country's capitol city (Zealandia, n.d.). The predator-proof fence is 8.6 kilometers in length and encompasses an area of 225 hectares (Zealandia, n.d.) (Figure 1-3). Construction of the fence was completed in 1999 and thence began intense predator eradication efforts (Zealandia, n.d.). All mammals (except for mice and humans) were eradicated from the preserve by 2000, allowing for the

reintroduction of endangered reptiles, insects and birds, such as the pāteke (Zealandia,

n.d.).
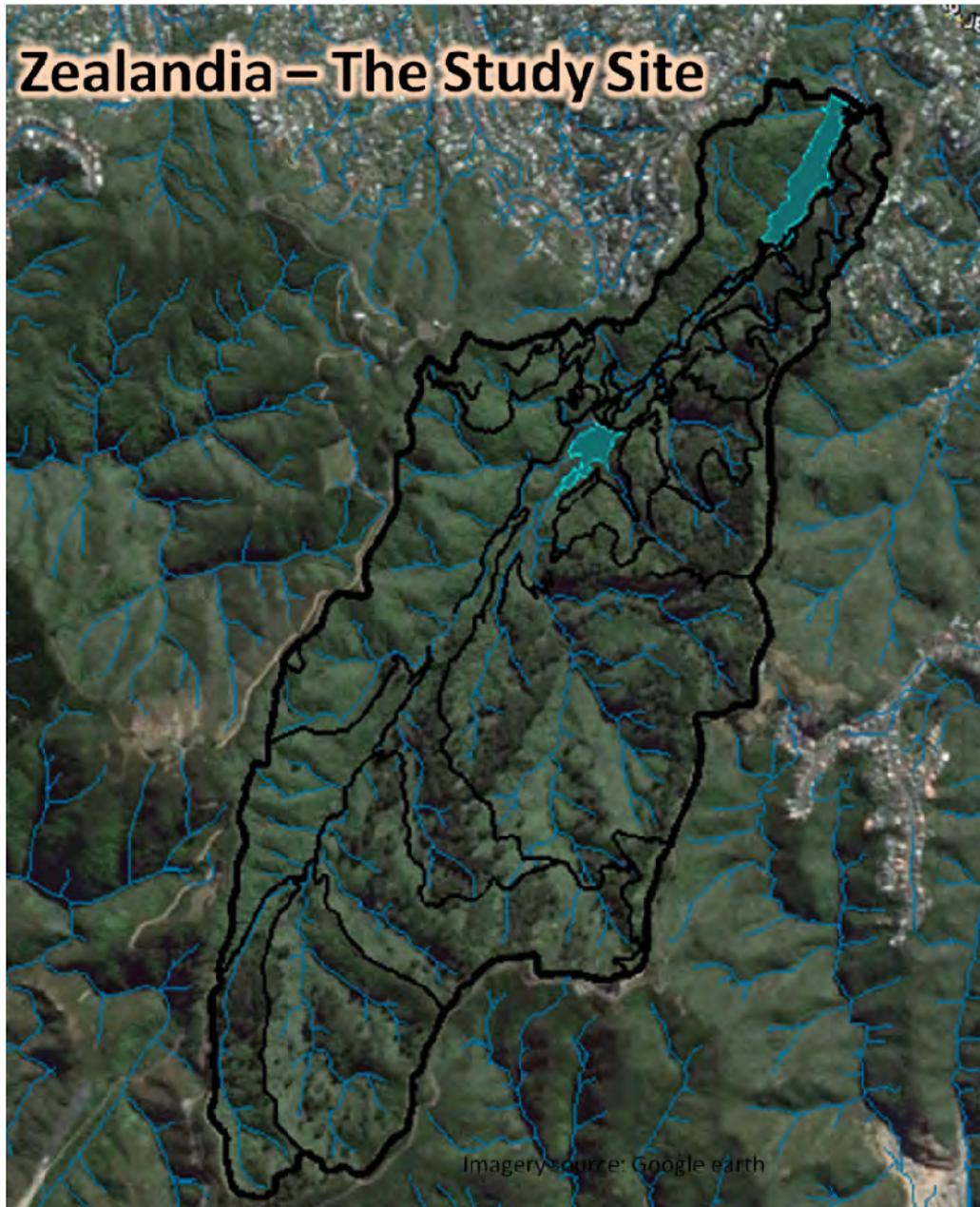
Figure 1-3. Zealandia – the study site, with 8.6-kilometer long fence and public trails shown in black, and upper and lower lakes, streams and tributaries shown in blue.

The sanctuary extends approximately 3.3 kilometers from its northernmost tip to its southernmost tip and is approximately one kilometer wide at its center. The fence line runs nearly north-south along two parallel ridges. Between these ridges, the land slopes downward and meets in the center of the valley, where numerous tributaries from minor valleys within the preserve coalesce. The small tributaries within the southern and central portions of the sanctuary eventually converge into one of three prominent streams, which flow in a generally northern direction and feed the top dam. Tributaries in the northern portion of the sanctuary flow from hills to the east and west and feed either into Te Mahanga stream or directly into the lower dam. The lower dam is situated almost adjacent to the fence at the northern tip of the valley. It is approximately 430 meters long by 55 meters wide, with steep vegetated hills to the east and even steeper vegetated hills to the west. The dam is adjoined to the south by a small lawn area (takahē lawn) and manmade wetlands (Keith Taylor Wetlands). The top dam is approximately 120 meters long by 80 meters wide, with a secluded shallow wetlands area situated at its south end. Hills surrounding the top dam are more gradual. Numerous paved and gravel foot trails run throughout the preserve. However, trails south of the top dam are sparser and less often traversed. Save for a handful of small clearings along Lake Road (trail), all remaining portions of the sanctuary are forested.

In order to provide staff, volunteers and researchers with access to all remote parts of the sanctuary, transects have been flagged out at 50-meter intervals, which run parallel to one another and follow compass bearings, extending from the west fence line to the east throughout the entire sanctuary. Numbered markers are placed every 25 meters along each transect, marking predator bait stations, as well as providing an invaluable means of referencing location throughout the preserve.

1.4.2 History of pāteke at Zealandia

In November 2000, eight pāteke, provided by Ducks Unlimited, were released along the edges of the upper lake and along Te Mahanga and Keith Taylor Wetlands at Zealandia. This was followed by a top-up release of 10 pāteke in similar locations in April 2001 (Figure 1-4). Some birds' wings were temporarily clipped to ensure that they remain within the safety of the fence until acclimated to their new environment (KWS, 2004). Prior to release, all birds were given an overall health assessment and were fitted with unique metal identification bands as well as color bands to facilitate identification (KWS, 2004). Supplementary feeders were installed at the release sites for the first year to aid in their transition from captive to wild (KWS, 2004). Of the 18 originally-released pāteke, nine were fitted with transmitters in order to monitor their general movements and well-being (Zealandia Records).
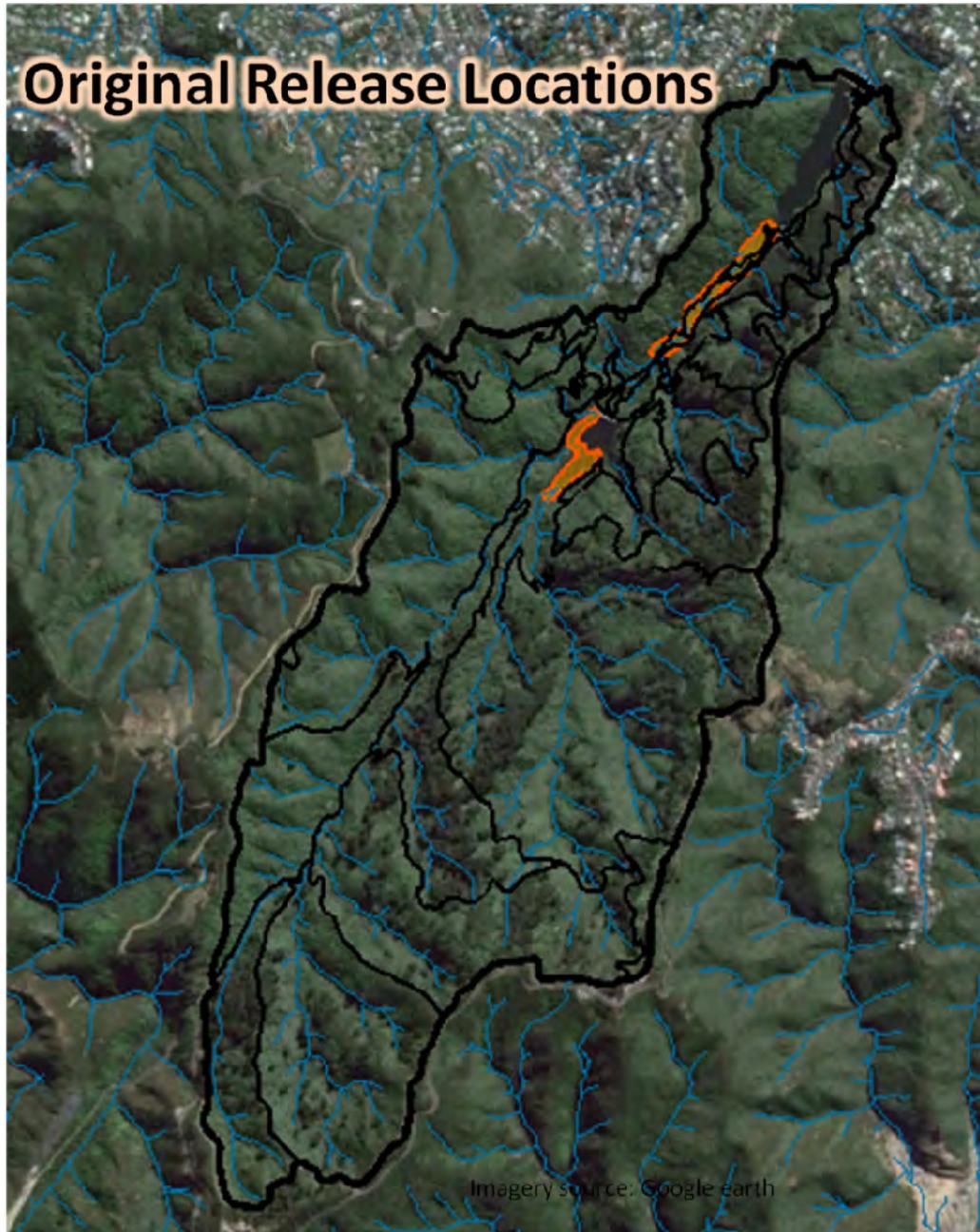
Figure 1-4. Original release locations of 18 pāteke in November 2000 and April 2001, shown in orange.

In their first year at the sanctuary, two birds were found dead. The cause of death was uncertain, but likely attributable to starvation and the birds' inability to make the transition from captive aviary-fed birds to wild (KWS, 2004). Two nests were

produced, one of which was lost to flooding (KWS, 2004). One duckling survived from the second nest (KWS, 2004). It should be noted that within the first few months following their release at Zealandia, several teal were tracked well away from the upper and lower dams. One individual was regularly observed near the western fence line ridge at transect QR and another roughly 250 meters upstream from the upper lake, near transect P (Zealandia Records).

In their second year (2002) at Zealandia, several pairs were noted to have nested, with 20% (12) of their ducklings fledging (KWS, 2004). Duckling mortality was attributed to flooded nests, failure to thrive and predation by natural predators including eels, harriers and falcons (KWS, 2004). In an effort to increase duckling survival, Zealandia placed supplemental feeders at all locations where mating pairs were identified (KWS, 2004). As a result, duckling survival for the following year rose to 80% (KWS, 2004).

In an effort to facilitate the monitoring of the pāteke population, cages were installed around feeders and were used to capture fledgling pāteke for banding purposes. Banding of fledglings was done as needed until 2007, and then resumed as part of this Master's thesis work from 2013 to 2015. To date, 100 pāteke have been banded at Zealandia. However, given the high duckling mortality rate, occurrence of natural predation within the fence and confirmed cases of dispersal outside the fence, the current population size is estimated to be much lower.

While there is a plethora of observations for pāteke located in the more easily-accessed and open areas of the sanctuary (i.e., around the perimeters of the upper and lower dams), forest observations are exponentially more sparse. Based on the results of a 2003 three-day audit using a pāteke search dog, as well as information collected

from the transmittered release birds at the onset of the pāteke reintroduction, pāteke do utilize forested areas of the sanctuary (KWS, 2004; Zealandia Records). However, very little was known of their distribution, abundance and behavior throughout the forested portions of the valley. From January 2013 to April 2013, I conducted a preliminary survey of the streams throughout Zealandia using two motion-sensing video cameras to determine whether teal were still distributed throughout the forested streams (Figure 1-5). Confirmation of their forest distribution provided justification for this project.
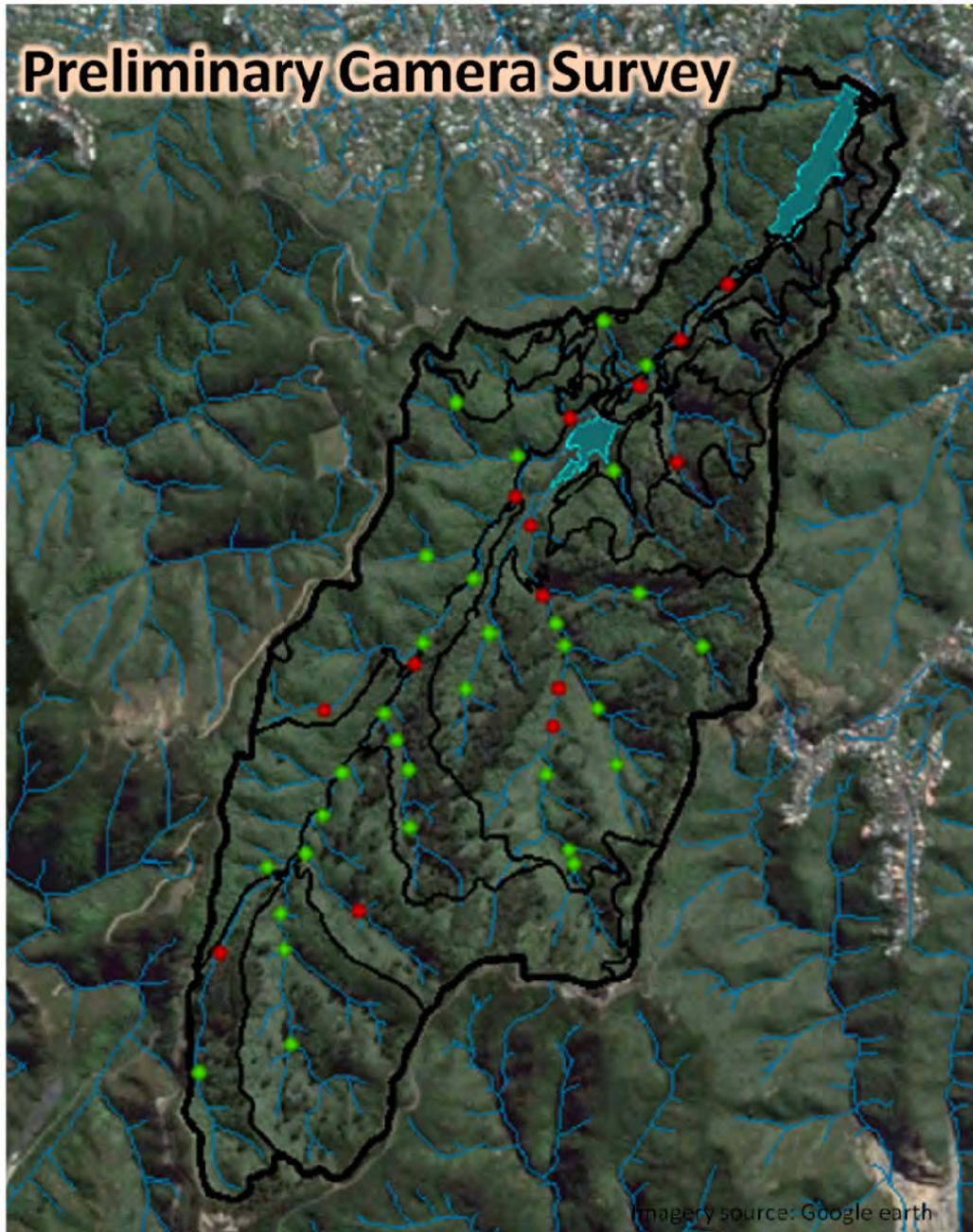
Figure 1-5. Preliminary camera survey results. Red camera locations indicate pāteke present. Green camera locations indicate pāteke not seen on footage.

1.5 Study objectives

The release of 18 pāteke into Zealandia – Karori Wildlife Sanctuary in 2000/2001 and their subsequent dispersal into the forested portions of the sanctuary provided the opportunity to evaluate pāteke habitat use in a predominantly forested setting for the first time. The overall aims of this study are to evaluate how pāteke utilize forested habitat and determine whether forested sanctuaries fenced to exclude mammalian predators provide suitable habitat for the endangered brown teal.

The primary aims of this study were:

1. To identify the home range attributes of pāteke at Zealandia through the use of telemetry. It is hypothesized that home ranges for pāteke living further from lakes will be significantly larger than home ranges of pāteke living along lake edges. It is further hypothesized that individual (or mating pair) home ranges will have minimal overlap with those of other pāteke or pairs.

2. To identify roosting patterns of pāteke at Zealandia through the use of telemetry. It is hypothesized that pāteke will consistently roost in one or a few locations, thus spending most of their roosting time within core areas of their individual home ranges. It is also hypothesized that roost locations for forest dwellers will vary seasonally, in relation to flocking season.

3. To identify foraging patterns of pāteke at Zealandia through the use of telemetry and motion-sensing cameras. It is hypothesized that individuals or pairs will consistently forage along the same section(s) of stream and that linear foraging ranges of bush pāteke will be longer than those of lake pāteke. It is anticipated that a greater number of individuals will overlap at cameras proximate to the flock site and that

locations proximate to the flock site will have a higher frequency of pāteke camera recordings.

4. To identify whether fenced forested sanctuaries, such as Zealandia, provide suitable habitat for the endangered brown teal. Monitoring was undertaken to ascertain survival rates of transmittered birds as well as breeding productivity of all teal within the sanctuary. All teal captured throughout the study were weighed and given a general health assessment. A thorough review of all available Zealandia pāteke records was undertaken to evaluate trends in breeding productivity and potential decline in genetic diversity through observed lineages.

2   Home range size and spatial relationships

2.1   Introduction

The idea that animals utilize specific home ranges has been referenced in literature since at least 1861 (Darwin, 1861, as cited in Powell, 2012), and has played an increasingly significant role in understanding animal behavior and ecology throughout the years. The concept of a home range as it is understood presently has been defined by Burt (1943) as "*That area traversed by an individual in its normal activities of food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as in part of the home range.*" Although Burt had mammals in mind, specifically, when creating this definition, the concept applies to nearly all animals. When considering birds, and pāteke in particular, home range would most certainly also incorporate locations in which that individual regularly chooses to roost and flock.

More recently, Powell & Mitchell (2012) define home range more broadly as "*that part of an animal's cognitive map of its environment that it chooses to keep updated.*" Their work emphasizes the importance of identifying the driving forces behind *why* an animal revisits specific locations, rather than simply identifying the physical boundary of a home range and the number and distribution of GPS or telemetry points within it (Powell & Mitchell, 2012). It is well known that animal movements are largely driven by their desire to meet basic needs, including food, water, refuge, nesting, etc. Each species, and to an extent, each individual within that species, requires that their environment have specific attributes (i.e., slope, vegetative composition, aquatic features, understory density, etc.) in order to best meet those needs.

This chapter will identify the size of individual home range and the extent to which individual home ranges overlap with one another. Utilization distribution within the home range will also be evaluated in order to identify core areas of use. Pāteke home range will be largely defined by where the individuals choose to roost and forage. These two aspects of their home range will be discussed in greater detail in chapters 3 and 4, respectively.

2.2   Objectives

This part of the study aims to identify the home range attributes of pāteke at Zealandia through the use of telemetry. It is hypothesized that home ranges for pāteke living further from lakes ("bush pāteke") will be significantly larger than home ranges of pāteke living along lake edges ("lake pāteke"). It is further hypothesized that individual (or mating pair) home ranges will have minimal overlap with those of other pāteke or pairs.

2.3   Materials and methods

2.3.1   Banding and transmitter fitting

Ten pāteke were captured and fitted with transmitters between November 2013 and October 2014. Banding and transmitter fitting training were provided by Craig Shepherd and Jo Sim, respectively, at the Wellington Bird Rehabilitation Centre (WBRC), Ohariu Valley. One of the 10 transmittered birds was hand-netted at WBRC and released along a forested stream within Zealandia. The remaining nine were captured at Zealandia.

As the study concentrates on habitat use of forest-dwelling pāteke, seven transmitters were fitted to birds known to utilize forested habitat (this includes the one wild bird

transferred from WBRC and released in forested habitat). For the purposes of this study, these seven birds are referred to as "bush" or "forest" pāteke. The remaining three transmittered pāteke are referred to as "lake" pāteke. These are individuals who, prior to transmitter fitting, were observed to remain in specific locations along the lake edges (Figure 2-1).
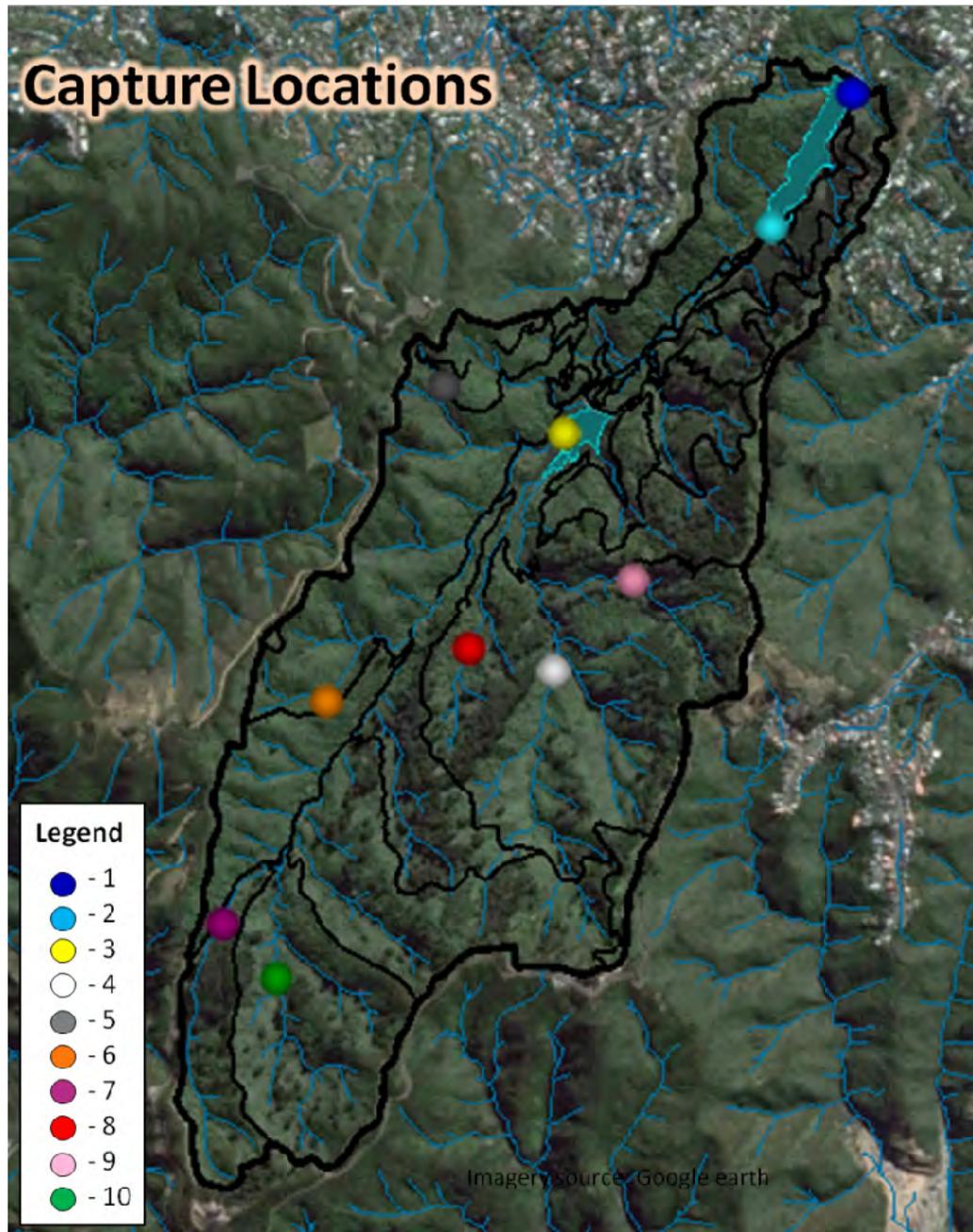
Figure 2-1. Capture locations of 10 transmittered pāteke. Birds 1 through 3 represent lake pāteke. Birds 4 through 10 represent bush pāteke. No. 8 represents release location of transferred bird.

Birds at Zealandia were captured using one of two methods. One lake bird was hand-fed and then hand-netted. The remaining eight study birds were keyed in to stationary feeders containing maize grits, which were positioned inside 1-meter x 1-meter x 2-

meter wire mesh cages. Lakeside cages were provided by Zealandia. Forest stream cages were provided by Fish & Game New Zealand.

Cages with feeders were placed along streams within the forested portions of Zealandia at six different locations, to ensure that the birds captured and fitted with transmitters were birds known to occupy forested habitat. The remaining three locations in which birds were captured and fitted with transmitters were along the edges of the upper and lower lakes.

Cages remained open during the period in which the birds were being keyed in to the locations. Once regular feeder patterns were established and arrival times determined through the use of camera traps, cages were set and manually closed using draw strings (Figure 2-2). Manual cage closure ensured that captured birds spent minimal time trapped, thus reducing stress to the animal. The two lake birds captured in cages were captured during the daytime. The six forest birds were captured after sunset.

Figure 2-2. Pāteke No. 4 enters set cage to use feeder (Photo screen shot from camera trap)

At least two experienced bird handlers were present at every capture. Upon capture, I would enter the cage and place any captured birds into individual cloth bird bags. Bagged birds would then be handed out to the assistant and placed in individual cardboard holding boxes to minimize exposure to light, movement and noise, in order to reduce stress while awaiting processing.

General health of all birds was visually assessed. Each bird was weighed and measurements were taken for length of bill, head + bill, tarsus and wing. If birds were previously banded, the band number was recorded and the band was replaced, if worn. All birds were fitted with metal identification bands as well as color bands. Metal bands were then coated with colored reflective tape to facilitate identification at night. Feather samples were taken for potential future DNA and/or stable isotope analysis. All birds were photographed for reference (Figure 2-3).

Figure 2-3. Attaching backpack harness-mounted VHF transmitter to pāteke captured at WBRC (Photo: J. McKenna)

At each capture location, birds were either caught individually, with a mate, or with a mate and offspring. At each location, the adult male was fitted with a transmitter. With the exception of one female who was fitted with a transmitter, only males were fitted with transmitters in an effort to minimize handling of potentially gravid females.

This study used Holohil RI-2B transmitters with a minimal 12-month battery life. Transmitters weighed 11 grams and were fitted to birds using a backpack harness mount with built-in linen weak-link thread. The weak-link is a safety feature of the harness, which breaks, should the harness become tangled or snagged, allowing the bird to be released. Transmitters were selected and attached in accordance with the requirements and procedures set forth in the DOC SOP for attaching radio and data-storage tags to birds (DOC, 2011).

Animal Ethics approval number 2013R11 was granted on 11 June, 2013 by the Victoria University of Wellington Animal Ethics Committee for this research project (Appendix 1). The New Zealand Department of Conservation issued permit number 36853-FAU for this research project on 10 October, 2013 (Appendix 2). Karori Wildlife Sanctuary Trust approved a contract for admission to undertake research on 26 February, 2013 (Appendix 3).

2.3.2   Use of telemetry to identify home range attributes

All tracking was done by foot using a Telonics TR4 receiver and handheld portable Yagi aerial antenna. Bird location points were collected using the homing in method. Due to the elusive nature of pāteke and the type of terrain and vegetation in which they live, visuals were not obtained for most observations. Rather, the location and

accuracy of each observation was estimated based on strength of signal as it related to antenna directionality, topography, vegetation density and age of transmitter.

Pāteke were tracked during the daytime to identify roosting locations. Daytime tracking was carried out at a minimum of five days per week. However, individuals who occupied more obscure locations and/or relocated their roost sites frequently, resulted in having fewer daytime observations. For all daytime tracking sessions, an initial comprehensive scan was undertaken at the top dam to determine presence/absence of all 10 transmittered birds at the flock site, located at the south end of the top dam.

Pāteke were tracked at night to identify locations in which they foraged. On average, night tracking was carried out once per month. Again, individuals who utilized more obscure locations and/or covered greater distances resulted in having fewer night telemetry fixes. As nightly telemetry tracking was impractical due to its labor-intensive nature, motion-sensing video cameras were used to collect the majority of information on night time foraging behavior of pāteke. Camera trap data were not included in the home range analysis since the nature in which they collect data is starkly different from the nature in which telemetry data are collected. Unlike telemetry, cameras acquire observations on a continuous basis at fixed locations, thus introducing highly auto-correlated and location-biased data into kernel density estimates (discussed below).

2.3.3 *Statistical Methodology*

All home range analyses were conducted using minimum convex polygon (MCP) (Mohr, 1947) and kernel utilization distribution (KUD) (Worton, 1989) methodology within the adehabitatHR package (Calenge, 2015) in R Studio Version 3.3.1 (R Core

Team, 2016). Polygons created in R were subsequently imported into QGIS Wien 2.8.7 and overlaid on Google Maps satellite imagery (QGIS, 2009). All analyses use only telemetry observations that were accurate to within 50 meters or less of the bird's actual location. Additionally, any observations at the beginning or end of the study that may have been influenced by placement of feeders were omitted to ensure that the findings reflect the birds' natural and unaltered behavior.

Home range areas and core areas for each bird were calculated using 95% and 50% minimum convex polygons, respectively. The MCP method constructs conservative home range and core area estimates by creating the smallest contiguous convex polygon which encompasses a chosen percentage of an individual's observed relocations. For the overall home range, "occasional sallies" are omitted by excluding the outer five percent of observations. Core areas of use are determined by identifying the MCP in which half of all observations are situated. The simplicity of this model and its effectiveness at creating a standard for the analysis of home ranges have made it one of the most commonly-used methods for home range analysis since its creation (Worton, 1995).

Home range areas and core areas were also constructed using 95% and 50% fixed kernel utilization distribution estimates, respectively. The KUD method provides a more complex and comprehensive means for characterizing home range in that it incorporates an estimate of the probable distribution of an individual's relocations (Worton, 1989). The KUD method is based on the concept of probability density estimation and thus produces a home range with a three dimensional construct, which can be depicted in layers (isopleths) using varying probabilities. Typically, 95% isopleths are used to show the home range and 50% isopleths are used to show the

core area(s) (Garrott & White, 1990). The primary advantage of the KUD method over the MCP method is that the core areas produced (using isopleths at 50%) can yield more than one polygon if relocations are clustered in more than one location.

Calculation of the probability distribution (formation of the kernel[s]) is based on the distance of each point from the others (i.e., the concentration of points within the latitudinal/longitudinal plane). By default, adehabitatHR utilizes a reference bandwidth to smooth the observed data in order to best fit the expected distribution. The reference bandwidth (h) assumes a unimodal distribution of the bivariate data by incorporating the standard deviation of all relocations using the following equation:

$$h = \sigma \times n^{-1/6}$$

where

$$\sigma = 0.5 \times (\sigma_x + \sigma_y)$$

and σ_x and σ_y are the standard deviations of the x and y coordinates, respectively (Calenge, 2015). However, because animals often concentrate their activity in several discrete locations, use of a bandwidth that assumes a unimodal distribution results in significant oversmoothing of the data (i.e., outcome predicts that the individual frequently utilizes areas that it doesn't use) (Calenge, 2015). One way to address this issue is to discard the reference bandwidth and instead allow AdehabitatHR to automatically calculate the smoothing parameter (bandwidth) using the Least Square Cross Validation (LSCV) method, which minimizes the Mean Integrated Square Error (MISE) (Calenge, 2015). The LSCV method, however, may fail to calculate an appropriate bandwidth for some data sets, particularly in cases where points are clustered (Gitzen et al., 2006).

When the two bandwidth methods described above are not suitable, any numeric value can be passed as the bandwidth, the most appropriate one of which can be selected based on trial and error and what outcome visibly matches the expected home range outcome most closely. This methodology is often the most appropriate choice (Silverman, 1986; Wand & Jones, 1995, as cited in Calenge, 2015). Kie et al. (2010) recommend that the bandwidth be chosen by identifying the smallest bandwidth which still produces a single polygon. This method reduces effects of over-smoothing that causes inflated home range sizes. Kie et al. (2010) further state that a bandwidth should be selected that produces a polygon most similar to that which would be expected based on data and the researcher's knowledge.

As the data sets for each of my birds are multimodal and as AdehabitatHR was unable to compute bandwidth based on LSCV, I have chosen the minimum bandwidth for each bird that produces a single polygon. It is often the case that even when a dataset-specific bandwidth is carefully selected through trial and error, the smallest-single-polygon output still drastically overestimates the actual home range of the animal. This conundrum commonly occurs when the input data points represent animals with linear home ranges, home ranges with sharp edges, or when the clusters of data points for an individual contain large spaces between them (Blundell et al., 2001; Getz & Wilmers, 2004; Hemson et al., 2005; Row & Blouin-Demers, 2006, as cited in Downs, 2008).

Complex linear home range analysis methods have been developed for use with animals who maintain linear home ranges (Ouellette & Cardille, 2011). Similarly, "clipping" methods have become increasingly popular for altering kernel-estimated home ranges with sharp edges or distinct physical boundaries by "clipping" out the

areas of the estimated home range that are known to not be used (Knight et al., 2009). However, no clear resolution has been devised to address the issue of clusters of concentrated relocations with large spaces between them.

Selection of bandwidth *a priori* produced realistic home ranges for seven of the 10 transmittered birds. Home ranges for the remaining three transmittered birds (birds 5, 6 and 8) were unrealistically large due to large empty spaces between their relocation clusters. Inclusion of these void areas for the purposes of forming a single polygon resulted in drastic over-smoothing. These void regions seemed only to be traversed by pāteke infrequently and at night, being used as travel corridors between core areas. This coupled with the infrequency with which night tracking was carried out resulted in data voids between core areas for these three birds. While my study specimens did show a marked reluctance towards flight as well as a strong preference to travel along streams at night based on camera trap observations, reducing over-smoothed home range sizes by creating complex linear home ranges or clipping their home ranges to fit along streams would have been too presumptuous.

Similar to but less rigid than the concept of home range "clipping", I added "corridor points" at 100 meter intervals along streams connecting core areas in order to coerce the estimated KUD home ranges into more realistic representations of the home ranges. One-hundred meter intervals were chosen because this allowed for the fewest number of points to be added, while still producing the desired effect of tapering the central portion of the home range boundary to loosely follow the stream corridor. Unlike linear home range or clipping methods, this method still allows the home range to include wide terrestrial buffers along either side of the stream, more accurately reflecting areas that were potentially used by the pāteke, while dramatically

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reducing the amount of unused space surrounding each kernel that was previously included within the home range estimate. Six corridor points were added for bird 5. Two corridor points were added for bird 6. Four corridor points were added for bird 8. Once these "corridor points" were incorporated, the standard bandwidth selection method was applied.

Birds 1, 6, 7, 9 and 10 each had far outlying points which likewise caused use of the standard bandwidth selection method to produce largely-inflated and unrealistic home ranges. Home range area plots were compared to determine which outlying point(s) created significantly larger and unrealistic home range estimates. The point(s) which were clearly outliers to the true home range were removed for these five birds, after which the standard bandwidth selection method was applied. As the standard convention for home range computation includes 95% of all observed relocations, the number of outlying points removed for any bird did not exceed 5%.

Survey bias during telemetry data collection caused observations at more easily-accessed locations (i.e., the flock site at the south end of the upper dam) to be over-represented for birds 4, 5, 6 and 8. To account for this, proportions of flock site observations to total observations were calculated for these four birds. As mentioned earlier, for every day of tracking, a scan was conducted from the upper dam for all 10 birds to determine whether they were at the flock site or further south in the bush. For every instance where a bird was observed to be far south in the bush and not in the flock site, but the actual location could not be determined due to time constraints, a "blank" bush observation was noted. These "blank" observations were then added to the total number of observations for the bird and the proportion of flock site observations to total observations was recalculated. The following equation was used

to calculate the appropriate number of flock site observations (y) to discount from the overall dataset for the purposes of calculating and plotting KUD home range:

$$100 \times \frac{\text{flock site fixes}}{\text{flock site + bush fixes}} = \text{A\%}$$

$$100 \times \frac{\text{flock site fixes}}{\text{flock site + blank + bush fixes}} = \text{B\%}$$

$$100 \times \frac{\text{X}}{\text{flock site + bush fixes}} = \text{B\%}$$

$$\text{flock site fixes - x = y}$$

The home range area sizes did not meet the parametric assumption of variance homogeneity, so a Wilcoxon rank-sum test was used to determine difference between lake pāteke and bush pāteke home range sizes.

As mentioned previously, kernel density estimates provide a more comprehensive and complex means of home range analysis, and so are believed to produce more accurate representations of actual home range. Thus, home range overlap was calculated using 95% KUD home range areas. Overlap was calculated using the following equation described by Poole (1995):

$$100 \times \frac{2 \times \text{area of overlap}}{\text{home range of animal A + home range of animal B}}$$

2.3.4   Mortality

The fate of each bird was accounted for at the end of the study and consideration was made as to the probable cause of death for each deceased bird. Rate of mortality was calculated.

2.3.5   Genetic Diversity

A review of literature of genetic diversity in pāteke was conducted, with specific regard to genetic diversity in the pāteke captive breeding program, from which Zealandia's founder population was established. Careful review was undertaken of Zealandia records as well as observations made throughout the study to determine parentage of all known pāteke nests at Zealandia, since the re-introduction of pāteke. Each known nest was given a designation of 'V' (viable – parents were either original release birds, or known descendents of unrelated lineage), 'I-sc' (inbred-same clutch – parents were born from the same clutch), 'I-dc' (inbred-different clutch – parents were born from different clutches but share the same parents), or 'U' (unknown – lineage of one or both parents in unknown).

2.4   Results

2.4.1   Capture and Telemetry

Ten pāteke were captured, banded and fitted with transmitters between November 2013 and October 2014 (Table 2-1). Telemetry fixes for natural behavior were collected for the 10 study birds between May 2014 and January 2016, after which, birds were recaptured, weighed and transmitters and color bands were removed. Average weight for transmittered male pāteke was 661.67 grams (SD = 71.15) at capture and 630 grams (SD = 71.55) at recapture. The one transmittered female was

not included in the average. Average weight of birds pre- and post-transmitter both fall within the range of expected male pāteke weight.

Table 2-1. Pāteke capture/recapture information and telemetry fixes.

Bird ID	Sex	Age at Capture (yrs)	Weight at Capture (grams)	Capture Date (d/m/y)[1]	Last Natural Observation (d/m/y)	Condition on Recapture	Weight at Recapture (grams)	Total No. Fixes
1	M	unk	610	2/05/2014	12/01/2016	Healthy	560	155
2	M	10	770	3/07/2014	26/09/2014	Deceased	NA	35
3	M	10	630	6/06/2014	3/01/2016	Healthy	NA	220
4	M	11	640	16/06/2014	14/07/2015	Healthy	650	141
5	M	unk	690	22/08/2014	8/10/2015	Deceased	NA	106
6	M	unk	725	6/08/2014	10/11/2015	Very Thin	550	100
7	M	11	650	4/07/2014	26/10/2015	Healthy	700	95
8	M	unk	530	11/05/2014	29/09/2015	Healthy	600	59
9	F	14	940	20/10/2014	6/10/2015	Deceased	NA	34
10	M	14	710	9/10/2014	10/11/2015	Healthy	720	59

Note
1. Bird no. 1 was fitted with a transmitter on 13/11/2013. Date shown reflects start of observation of natural behavior.

In an effort to supplement information collected on transmittered birds, and to gain a better understanding of overall population dynamics, efforts were made to band and measure as many pāteke as possible. In addition to the 10 transmittered study birds, an additional two males, seven females, and nine juveniles from two clutches were captured, weighed and banded throughout the course of the study (Table 2-2). Average weight at capture for male pāteke was 649.55 grams (SD = 70.02). Average weight at capture for female pāteke was 795.63 grams (SD = 138.45). Average weight at capture of juvenile pāteke was 489.44 grams (SD = 39.09).

Table 2-2. Pāteke capture information

Bird ID	Sex	Age at Capture (yrs)	Weight at Capture (grams)	Capture Date (d/m/y)
11	F	0.4	480	29/09/2014
12	F	10	910	30/05/2014
13	F	unk	850	6/06/2014
14	F	15	690	31/07/2015
15	F	14	950	22/08/2014
16	F	unk	570	29/09/2014
17	M	unk	570	29/09/2014
18	F	unk	695	6/08/2014
19	F	13	760	4/07/2014
20	M	unk	620	20/10/2014
21	M	0.4	485	29/09/2014
22	M	0.25	450	4/07/2014
23	F	0.4	510	29/09/2014
24	F	0.4	490	29/09/2014
25	unk	0.25	530	4/07/2014
26	unk	0.4	550	29/09/2014
27	unk	0.25	490	4/07/2014
28	unk	0.25	420	4/07/2014

In several cases, the plastic color bands fitted around pāteke tarsi became brittle and/or loose, and caused injury to the hind claw of the bird. In these cases, birds were caught as soon as possible and color bands were removed. In all cases, the birds recovered. As a precaution, color bands were removed from all recaptured birds at the end of the study.

Based on observations in the field as well as careful review of camera footage, the pāteke population at Zealandia was estimated to be between 40 to 50 adult birds at the end of the study. Thus, it is important to note that the results and discussion provided herein are only representative of the 10 study birds and that other non-transmittered pāteke were present throughout the preserve, as observed in footage from the camera traps as well as direct observation on the lakes. These "others" typically included

females which appeared to share similar home ranges to their mates, and a handful of other unbanded and banded individuals and pairs.

2.4.2   Home Range Size

Prior to KUD analysis, data were adjusted to account for survey bias at the flock site for birds 4, 5, 6 and 8 (Table 2-3).

Table 2-3. Breakdown of flock site, bush, and "blank" telemetry fixes for birds 4, 5, 6 and 8.

Bird ID	Flock Site Fixes	Bush Fixes	Total Fixes	% Fixes at Flock Site	Blank Bush Fixes	Bush + Blank Fixes	Total Fixes	Adjusted % Fixes at Flock Site
4	116	25	141	82.27%	12	37	153	75.82%
5	79	27	106	74.53%	55	82	161	49.07%
6	50	50	100	50%	76	126	176	28.41%
8	16	43	59	27.12%	108	151	167	9.58%

I calculated home range and core area sizes for 10 pāteke who had between 34 and 220 total telemetry fixes. Mean and standard deviation were calculated for lake pāteke and bush pāteke home ranges and core areas (Table 2-4). Under both the MCP and KUD analyses, home ranges and core areas were larger for bush pāteke than for lake pāteke (Figure 2-4 and Figure 2-5).

Table 2-4. Mean and standard deviation (SD) for 95% and 50% MCP and KUD home range and core area sizes for lake pāteke (1 – 3) and bush pāteke (4 – 10) in hectares.

Bird ID	95% MCP	50% MCP	95% KUD	50% KUD
1	3.38	1.21	5.88	1.39
2	0.40	0.03	1.05	0.19
3	1.75	0.18	3.63	0.63
Mean	1.84	0.47	3.52	0.74
SD	1.49	0.64	2.42	0.61
4	5.16	0.21	8.51	0.99
5	29.63	1.03	37.35	3.76
6	44.34	13.39	43.85	6.60
7	3.74	0.15	7.70	1.04
8	27.45	9.18	31.28	6.35
9	4.30	0.05	6.80	0.92
10	26.91	13.01	37.46	6.77
Mean	20.22	5.29	24.71	3.78
SD	15.91	6.3	16.35	2.8
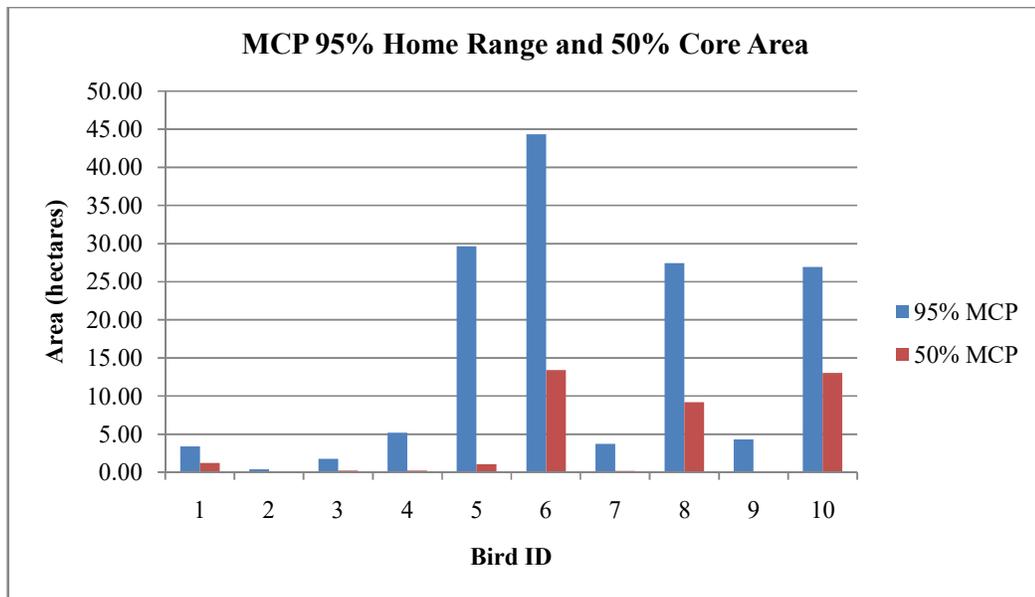
Figure 2-4. MCP 95% home range and 50% core areas for lake pāteke (1-3) and bush pāteke (4-10).
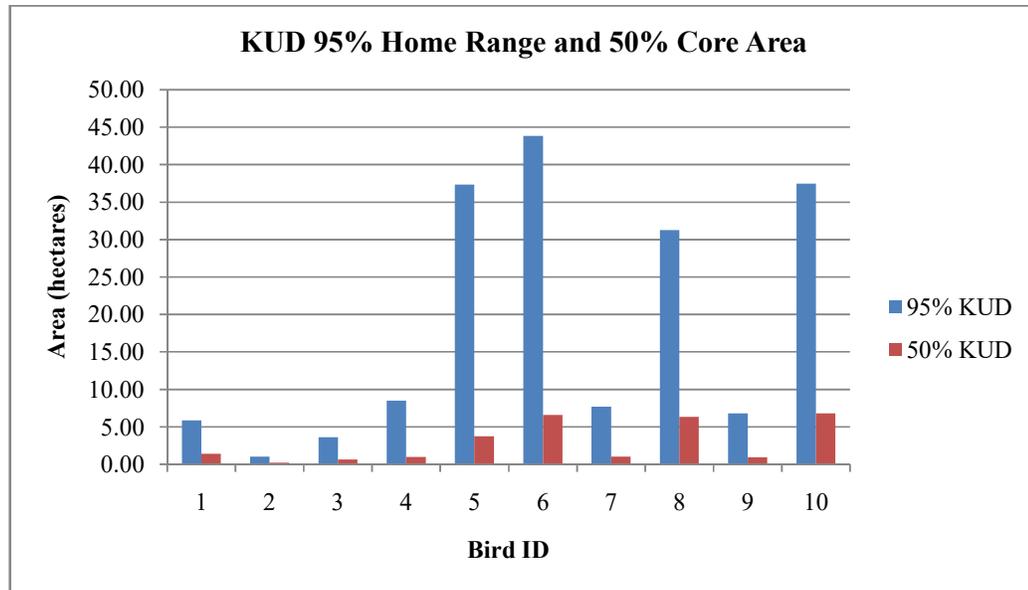
Figure 2-5. KUD 95% home range and 50% core areas for lake pāteke (1-3) and bush pāteke (4-10).

Using the MCP method, lake pāteke had a mean home range of 1.84 ha (SD = 1.49) and bush pāteke had a mean home range of 20.22 ha (SD = 15.91). Lake pāteke had a mean core area of 0.47 ha (SD = 0.64) and bush pāteke had a mean core area of 5.29 ha (SD = 6.3).

Using the KUD method, lake pāteke had a mean home range of 3.52 ha (SD = 2.42) and bush pāteke had a mean home range of 24.71 ha (SD = 16.35). Lake pāteke had a mean core area of 0.74 ha (SD = 0.61) and bush pāteke had a mean core area of 3.78 ha (SD = 2.8).

Maps depicting the 95% and 50% KUD and MCP home ranges and core areas as well as telemetry observation points for all 10 birds are included in the pages below (Figure 2-6 through Figure 2-15).
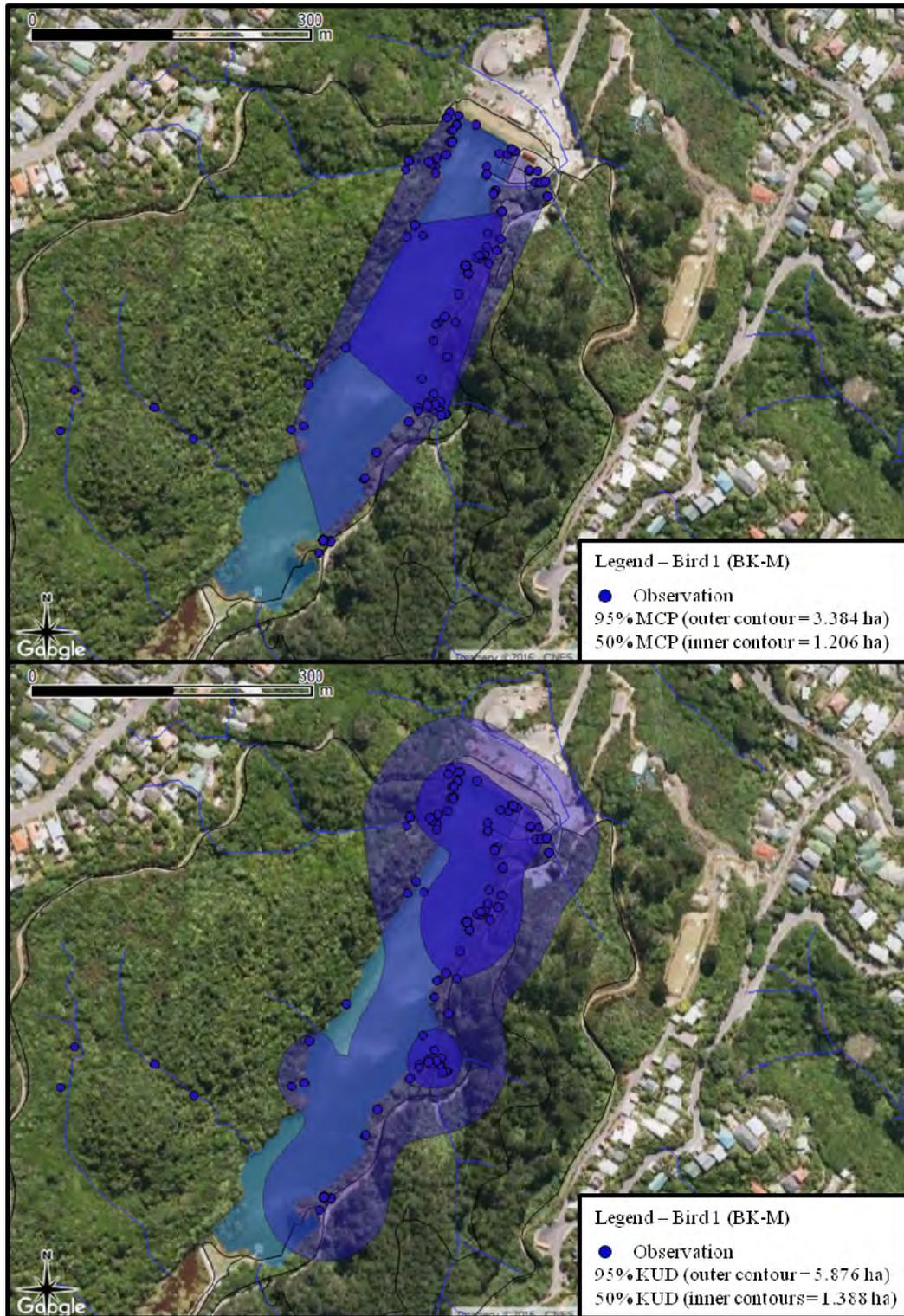
Figure 2-6. 95% and 50% home range contours for bird 1 (MCP above, KUD below).
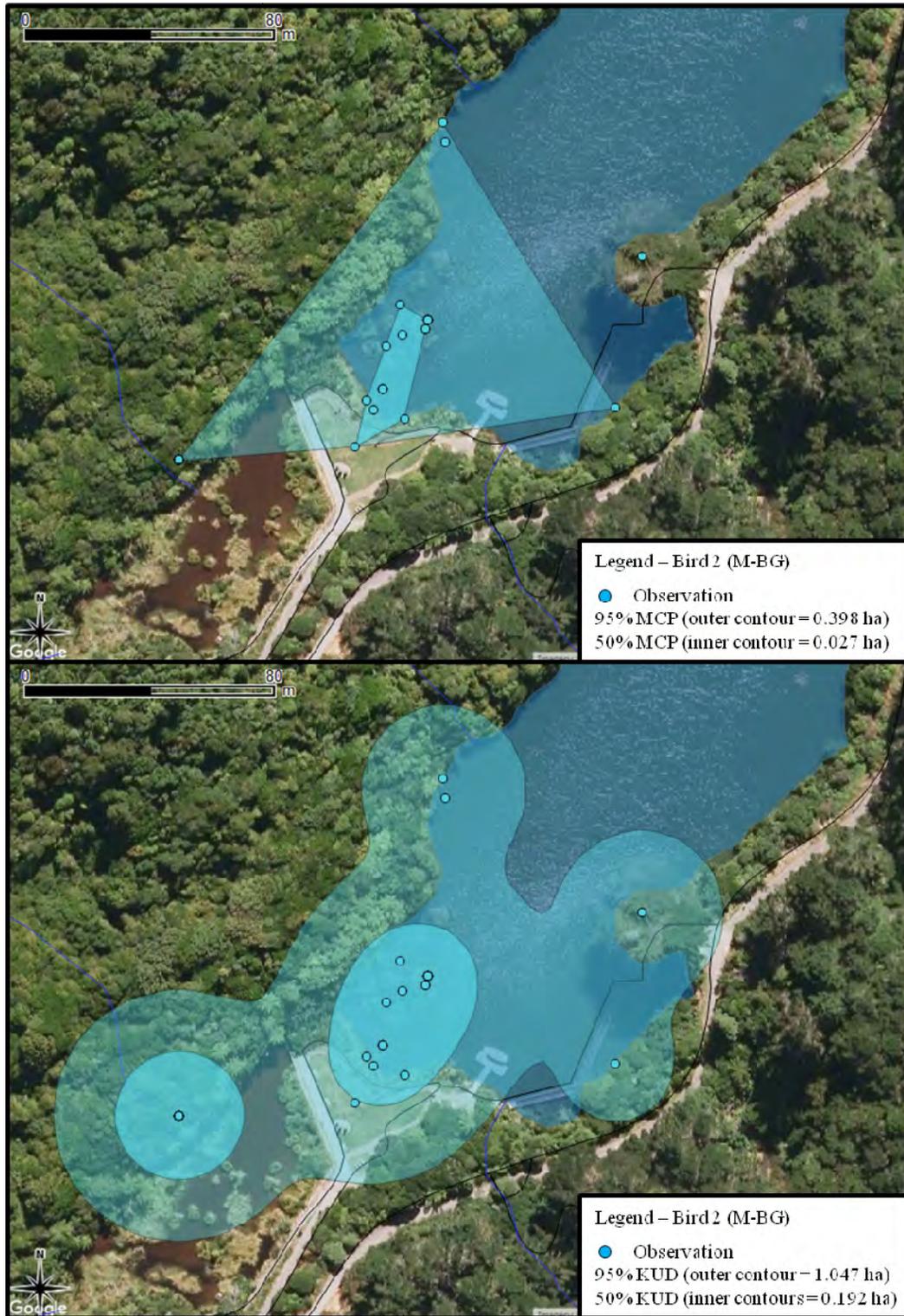
Figure 2-7. 95% and 50% home range contours for bird 2 (MCP above, KUD below).
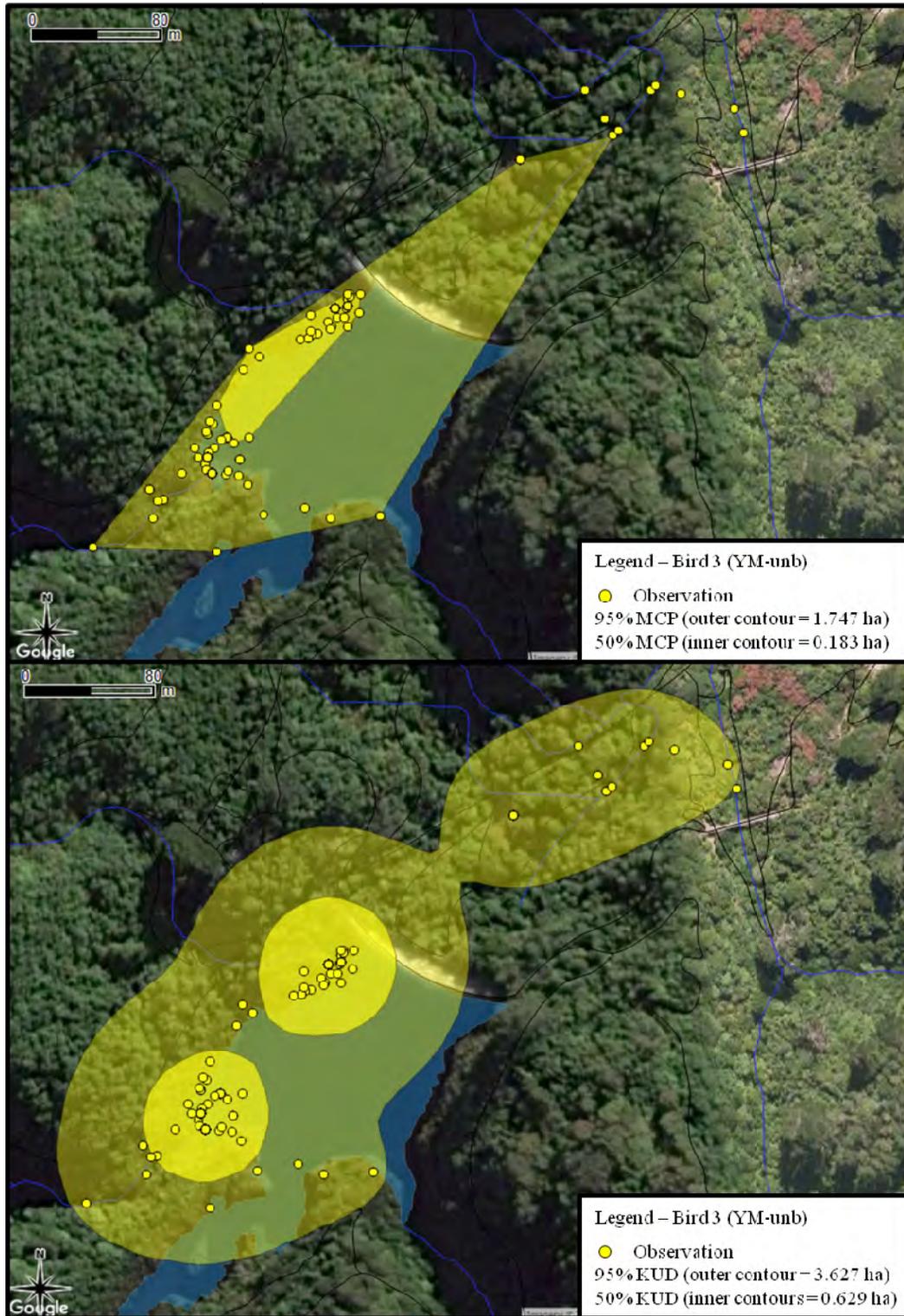
Figure 2-8. 95% and 50% home range contours for bird 3 (MCP above, KUD below).

Legend – Bird 4 (WK-M)

○ Observation
95% MCP (outer contour = 5.165 ha)
50% MCP (inner contour = 0.211 ha)

Legend – Bird 4 (WK-M)

○ Observation
95% KUD (outer contour = 8.505 ha)
50% KUD (inner contour = 0.989 ha)

Figure 2-9. 95% and 50% home range contours for bird 4 (MCP above, KUD below).

Legend – Bird 5 (KK-M)
● Observation
95% MCP (outer contour = 29.633 ha)
50% MCP (inner contour = 1.034 ha)

Legend – Bird 5 (KK-M)
● Observation
95% KUD (outer contour = 37.347 ha)
50% KUD (inner contours = 3.764 ha)
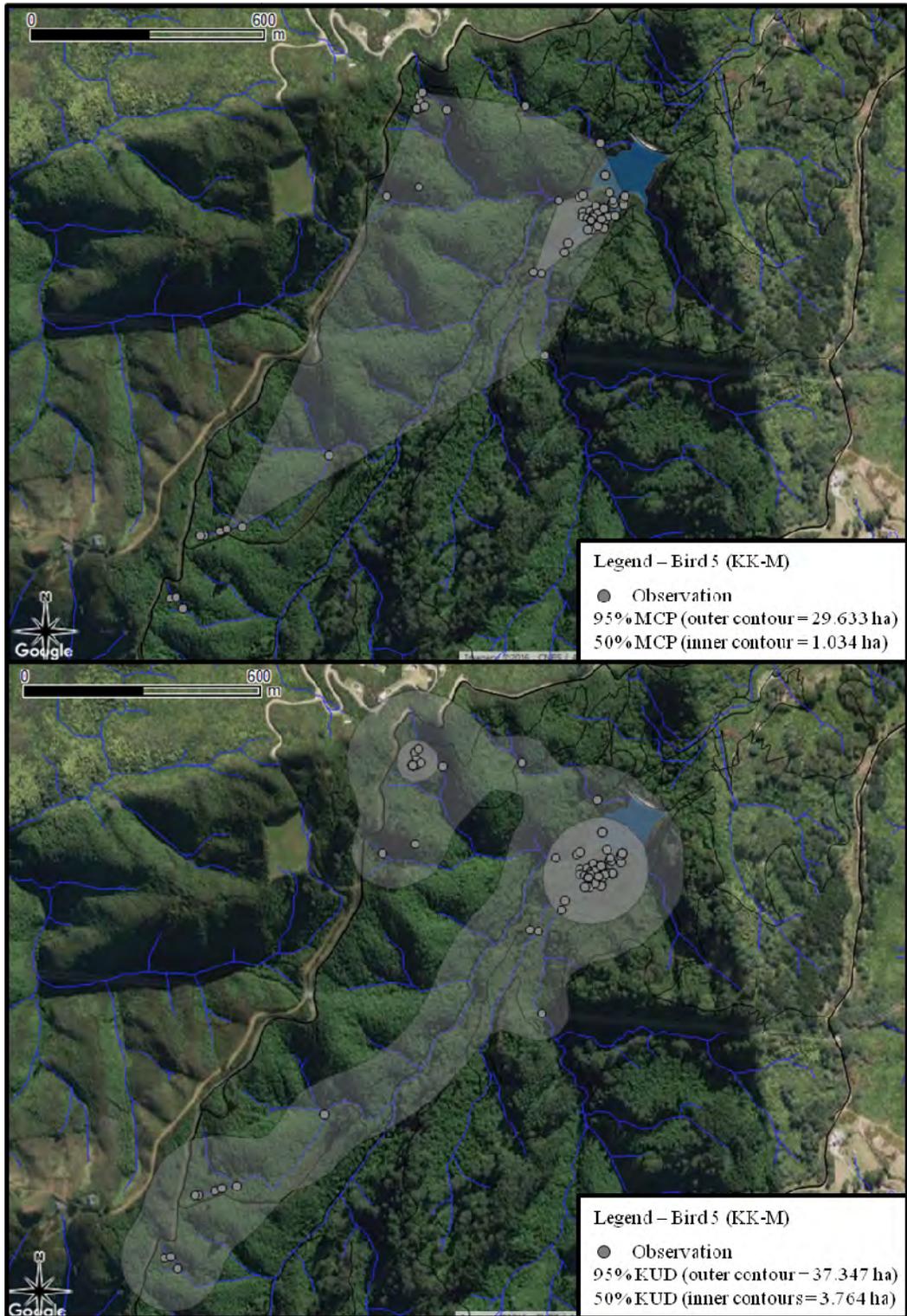
Figure 2-10. 95% and 50% home range contours for bird 5 (MCP above, KUD below).
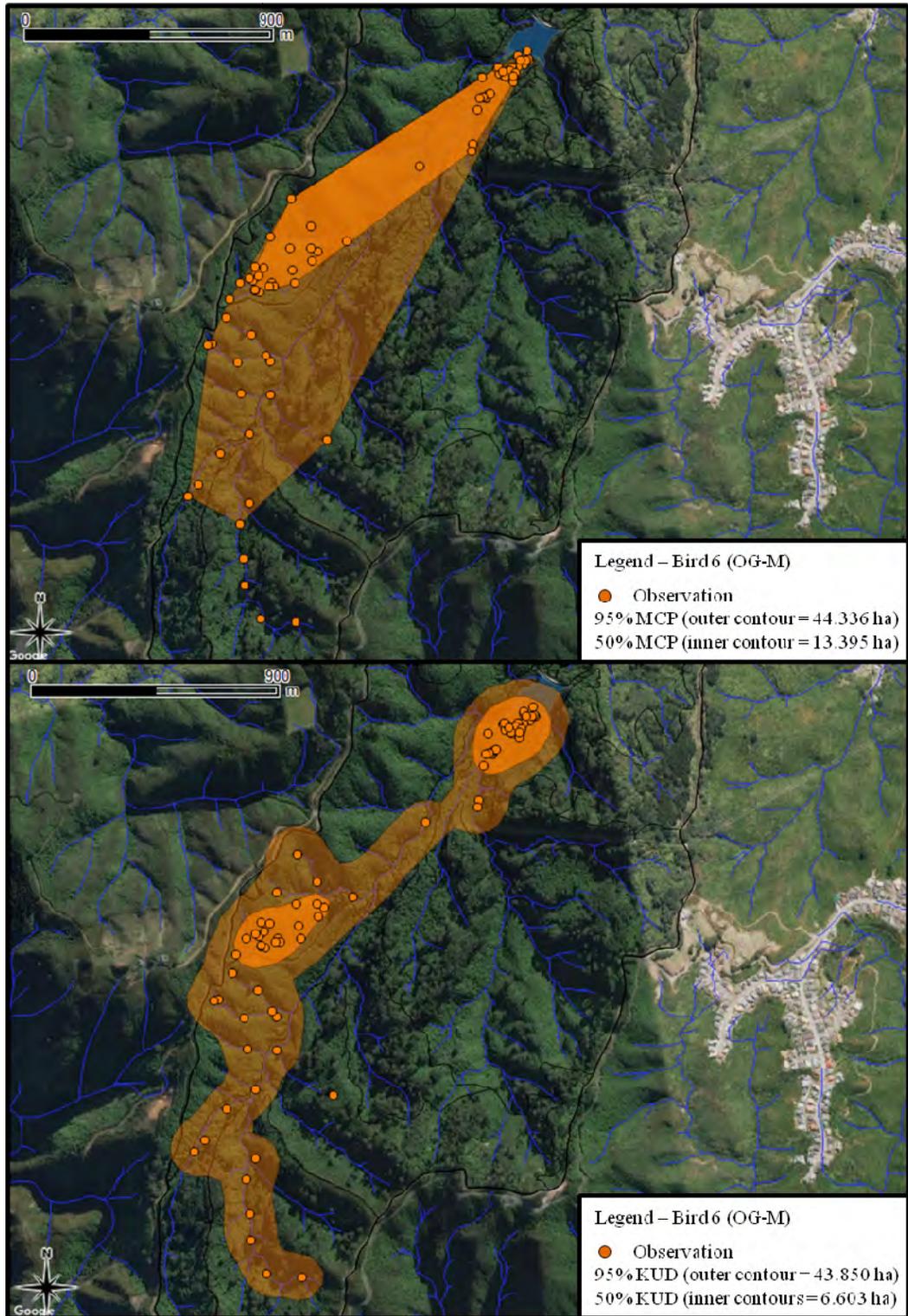
Figure 2-11. 95% and 50% home range contours for bird 6 (MCP above, KUD below).

Figure 2-12. 95% and 50% home range contours for bird 7 (MCP above, KUD below).

Legend – Bird 8 (M-RK)
● Observation
95% MCP (outer contour = 27.447 ha)
50% MCP (inner contour = 9.178 ha)

Legend – Bird 8 (M-RK)
● Observation
95% KUD (outer contour – 31.284 ha)
50% KUD (inner contours = 6.355 ha)
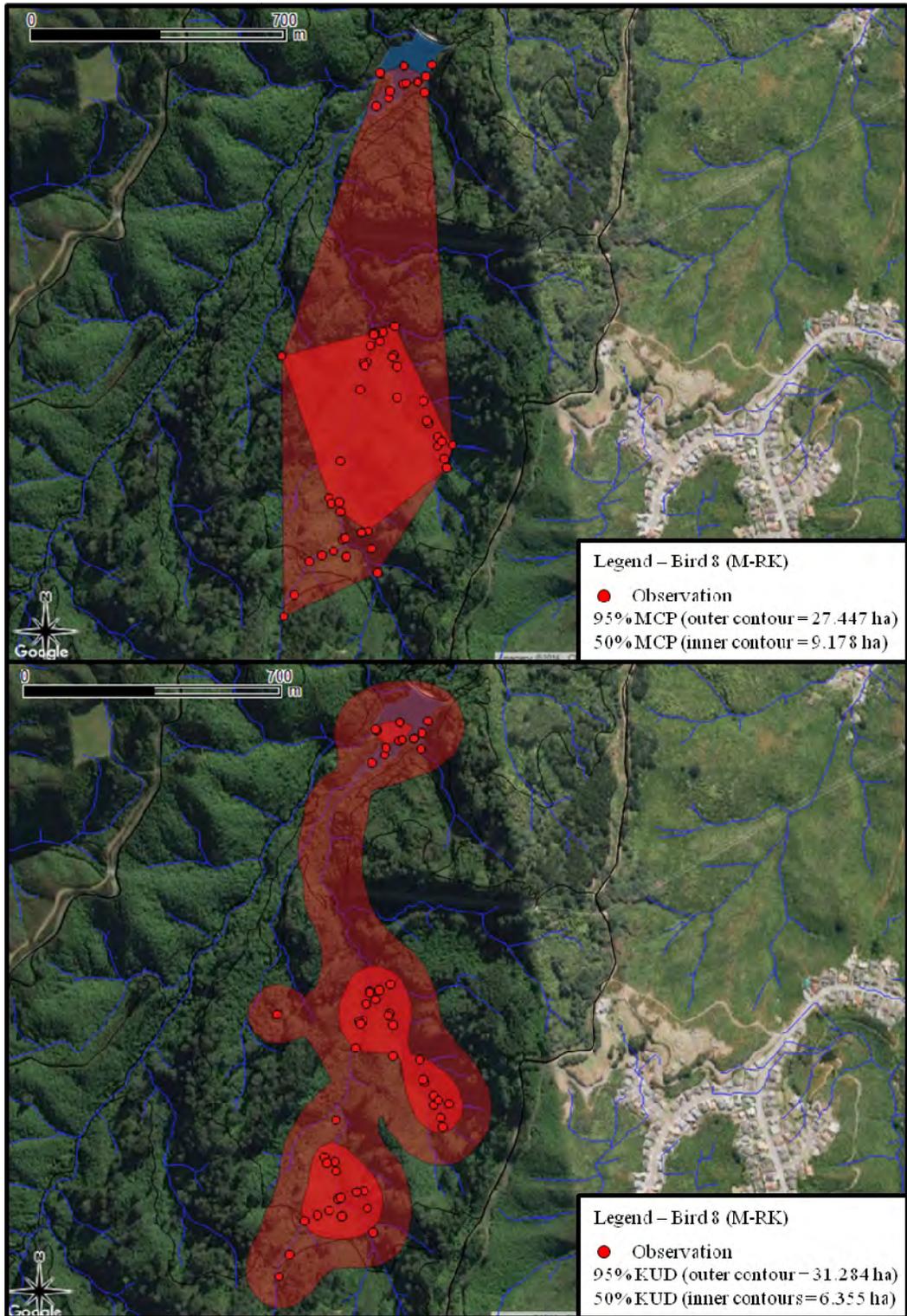
Figure 2-13. 95% and 50% home range contours for bird 8 (MCP above, KUD below).

Figure 2-14. 95% and 50% home range contours for bird 9 (MCP above, KUD below).
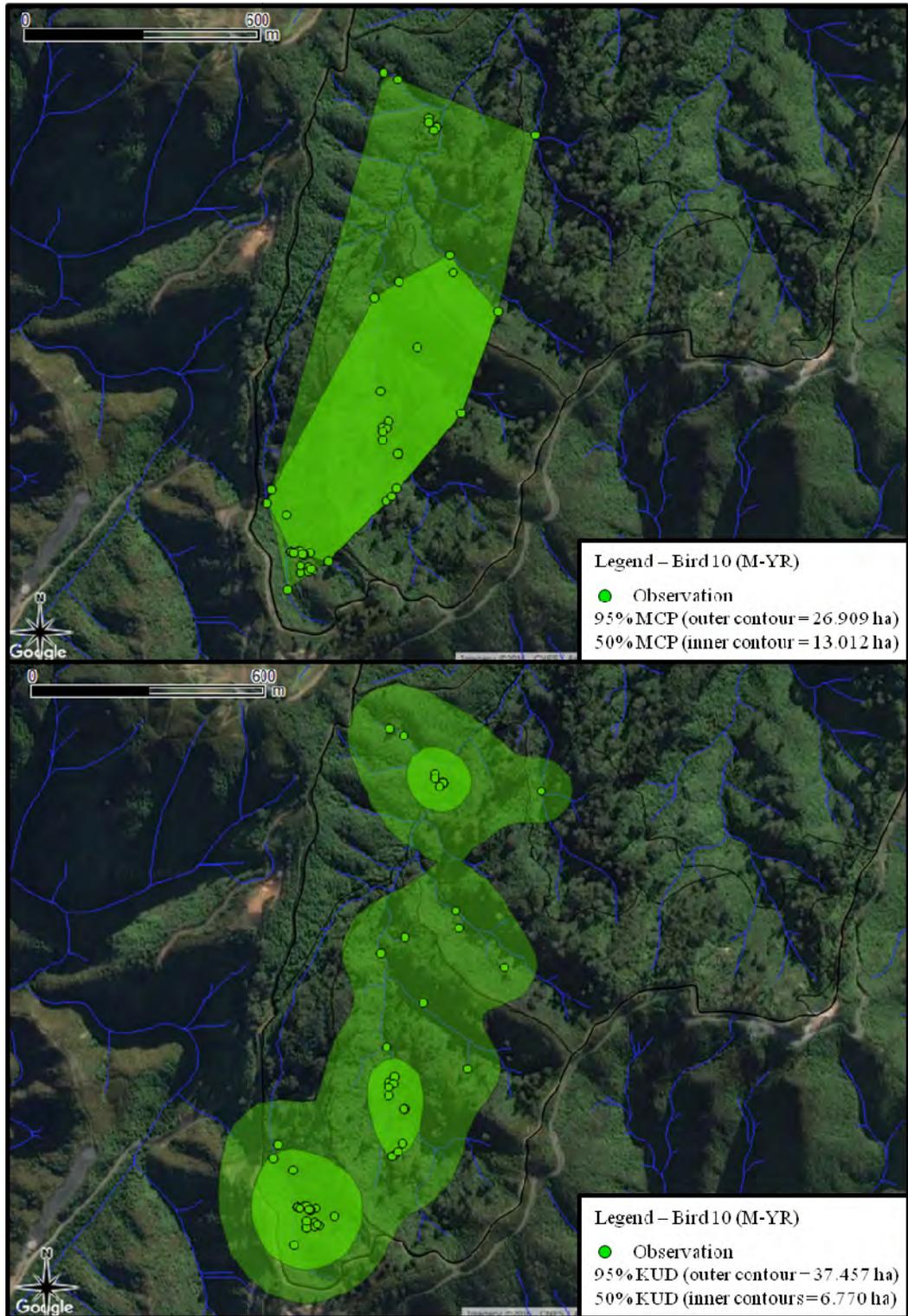
Figure 2-15. 95% and 50% home range contours for bird 10 (MCP above, KUD below).

The 95% MCP home ranges of lake pāteke were significantly smaller than that of bush pāteke (P = 0.017). The 50% MCP core areas of lake pāteke were not significantly smaller than that of bush pāteke (P = 0.383). The 95% KUD home ranges of lake pāteke were significantly smaller than that of bush pāteke (P = 0.017). The 50% KUD core areas of lake pāteke were not significantly smaller than that of bush pāteke (P = 0.118).

2.4.3 Home Range Overlap

Home range overlap occurred at varying degrees between the 10 transmittered birds, with the greatest percentage of overlap occurring between pāteke nos. 5 and 6 at 71.54% home range overlap (Table 2-5). Individuals who overlapped with the highest number of other birds were those four who frequented the flock site (4, 5, 6 and 8). Locations in which each home range overlapped are shown below (Figure 2-16).

Table 2-5. Extent of 95% KUD home range overlap between study birds.

	1	2	3	4	5	6	7	8	9	10
1	x	6.09%	x	x	x	x	x	x	x	x
2	6.09%	x	x	x	x	x	x	x	x	x
3	x	x	x	17.89%	12.60%	8.06%	x	13.25%	x	x
4	x	x	17.89%	x	24.07%	19.97%	x	28.01%	x	x
5	x	x	12.60%	24.07%	x	71.54%	x	22.29%	x	5.84%
6	x	x	8.06%	19.97%	71.54%	x	22.51%	17.82%	x	33.14%
7	x	x	x	x	x	22.51%	x	x	x	18.15%
8	x	x	13.25%	28.01%	22.29%	17.82%	x	x	28.22%	x
9	x	x	x	x	x	x	x	28.22%	x	x
10	x	x	x	x	5.84%	33.14%	18.15%	x	x	x

54
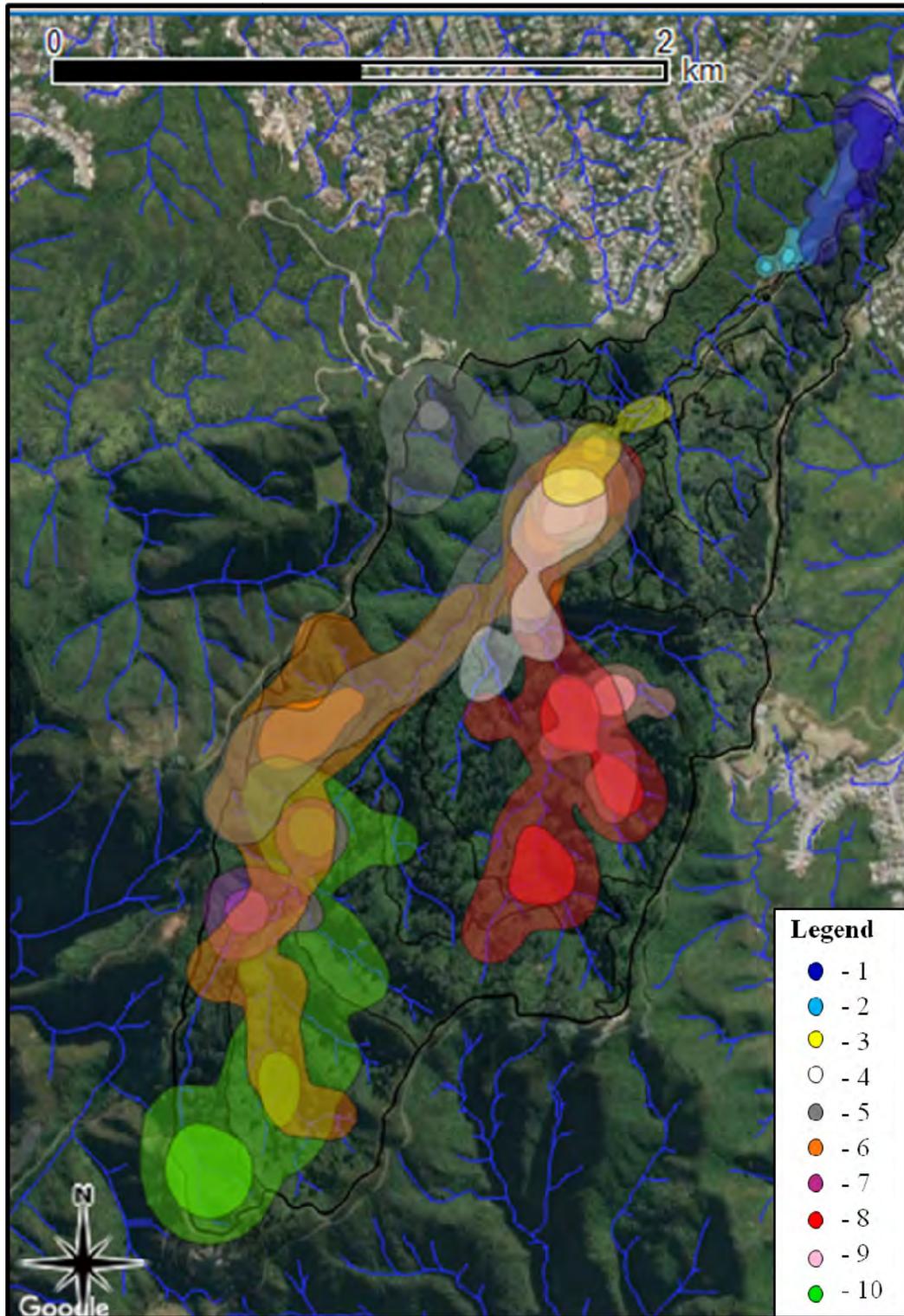
Figure 2-16. KUD home ranges and core areas for all 10 study birds, showing extent and locations of overlap.

2.4.4 Mortality

Of the 10 transmittered birds, three died during the course of the study. Bird no. 2 was not recovered until approximately four months post mortem and only a skeleton remained. However, based upon previous telemetry fixes, he likely died in late September or early October 2014. Bird nos. 5 and 9 were each recovered between two and three weeks post mortem. Bird 5 was recovered on 8 October 2015 and bird 9 was recovered 6 October 2015. Due to time elapsed since death, none of the three birds were sent for necropsy. No obvious cause of death was apparent. However, birds 5 and 9 were extremely thin, thus suggesting starvation as a cause of death. There was no indication in any of the three deaths that the transmitter or harness contributed to the cause of death. Ultimately, transmittered birds experienced a 30% mortality rate over the duration of the study.

2.4.5 Genetic Diversity

A previous study evaluated genetic diversity of pāteke at both remnant populations (Mimiwhangata and Great Barrier Island), within the captive-bred population (derived solely from that of Great Barrier Island) and within Zealandia's population, among others (Bowker-Wright et al., 2012). While the Mimiwhangata population was found to support the greatest amount of genetic diversity (11 unique mtDNA haplotypes), the study revealed very little genetic diversity within the Great Barrier Island population (two haplotypes) (Bowker-Wright et al., 2012). This limitation in genetic diversity was magnified upon creation of the captive-bred stock (one haplotype identified) and dispersed throughout the reintroduction sites, including Zealandia.

Zealandia's pāteke population size was estimated to be between 40 and 50 adults within the fenced sanctuary. Birds ranged from one year old to 15 years old, with

several of the 18 founder birds still healthy and residing within Zealandia. A review of Zealandia's records, as well as observations made over the course of the study indicates that, since their release at Zealandia, pāteke have produced 59 known nests. It is likely, however, that many more have gone unobserved and/or unreported. Parental identity and lineage (back to 2001) were confirmed for 37 of these 59 nests. Of these 37 nests, 19 nests, or 51.4%, were a product of inbreeding. This is based upon the assumption that all 18 introduced birds were not related. However, given that Bowker-Wright et al. (2012) determined that the inbreeding coefficient of the Great Barrier Island population was positive and significant, it is likely that the 18 founder birds of Zealandia were already at least distantly related.

2.5   Discussion

2.5.1   Home range size

Home range analyses were conservative in that the home ranges constructed were based solely on telemetry data (excluded camera trap data), the vast majority of which were collected during the daytime when pāteke were roosting. It is the habit of pāteke to forage up and down along streams and in the bush at night, sometimes covering impressive distances, before returning to their roost around dawn. Several individuals were observed via camera trap to be foraging well outside the home ranges delineated above. While this conundrum is noteworthy, a delineation of home ranges which incorporated the entire range of regular foraging grounds would not have significantly altered the results outlined above. Rather, lake pāteke home ranges would have remained virtually the same, while home ranges of bush pāteke nos. 4, 7 and 9 would have included areas further upstream, thus strengthening the argument that bush pāteke have significantly larger home ranges than lake pāteke.

At least two possible answers exist as to why bush pāteke tend to hold larger home range areas than lake pāteke. In some instances, larger home ranges or territories are indicative of fitter, more dominant animals, who are able to defend larger areas and thus retain more resources for themselves (Stamps, 1994). Alternatively, a larger home range could suggest that resources within that habitat are more sparse, requiring the animal to travel further to meet its needs for survival (Stamps, 1994).

Based on behaviors observed in camera trap data, the latter scenario would seem to hold more truth for pāteke. Here I provide an example. Bird 7 has a much smaller home range than bird 10 (7.699 ha compared to 37.457 ha). During the period of the study in which birds were being keyed in to feeders for capture, bird 10 fed nightly at a feeder within his own home range. After several weeks, bird 7 was seen foraging upstream as far as the feeder, where he immediately displayed dominance over bird 10 by aggressively attacking and chasing him away. Once bird 7 had discovered the feeder, this happened several more times. This interaction holds increased significance, as it occurred within the home range, and adjacent the core area, of the bird who was dominated. Moreover, bird 7 would likely be considered the more fit of the two birds since he has held the same mate for several years and since he produced two viable clutches throughout the course of the study – a feat no other forest bird has accomplished over the study. Bird 10 has no mate and thus produced no clutches. To add to this, while bird 7 is categorized as a bush pāteke, the main core area within his home range contains a small standing water feature which is an important food source for him and his mate.

The idea that bush pāteke maintain larger home ranges because resources are sparser gains additional support when considering foraging patterns of bird 6 towards the end

of the study. In the two months preceding his recapture for transmitter removal, bird 6 was observed to be foraging during the day as well as night, in locations far away from his typical locales, thus increasing his overall home range size. Daytime foraging was atypical behavior and indicated that he was likely not finding enough food to sustain himself during his nightly forages. Likewise, foraging along novel pathways could indicate insufficient food within his typical stream corridors. Upon recapture, he was observed to be very thin with a pronounced keel and a 24% decrease in overall body weight since initial capture. These two types of atypical behavior were also observed in bird 9 just prior to death.

As foraging is the activity which appears to create marked differences in home range size, it would suggest that food availability determines home range size to a large extent. However, even if it is true that smaller home ranges contain more concentrated food sources, this does not necessarily mean that they provide preferential habitat, and does not preclude forested habitat from being viable for pāteke. Factors other than food availability play a role in habitat selection. It is possible that the advantage of roosting in the bush, under the protection of dense vegetation, outweighs the costs of having to travel further for food at night. An additional benefit of bush life may also be that the habitat is less densely populated. Thus, individuals are safer from one another and invest less energy in defending resources.

2.5.2 Home range overlap

Evaluation of home range overlap concluded that all transmittered pāteke had home ranges which overlapped with between one and six other transmittered pāteke. The extent of overlap ranged from 5.84% (between the two lower lake pāteke) up to 71.54% (between bush pāteke 5 and 6). While there is some degree of correlation

between these figures and what was observed in the field, the overlap estimations are believed to be largely inflated for a few reasons.

Firstly, the analysis of overlap did not account for temporal differences. There were very few instances (other than at the flock site) where birds were observed to be within the same vicinity at the same time. This does not preclude them, however, from seeking the same resources. If both are dependent upon a finite resource at a given location, but seek it at different times, that could still be problematic for their well-being.

More notably, overlap estimates are considered to be inflated as a result of the method in which their boundaries were constructed. In the field, pāteke were in many cases seen to adhere to strict geological boundaries. For example, the northeast-pointing peninsula at the south end of the upper lake provided a distinct boundary between the flock site and the southern core area of lake bird 3 (Figure 2-8). Only six telemetry fixes out of 220 place lake bird 3 on the east side of this peninsula. However, the model of bird 3's home range incorporates this area. Likewise, only two out of 59 telemetry fixes for bird 8 and four out of 106 telemetry fixes for bird 5 lie west of this peninsula, but the western area is included in their home range boundaries. This suggests that their home ranges do not overlap to the extent suggested in Table 2-5 and in Figure 2-16.

Similarly, even a small amount of over-smoothing in the KUD analysis can lead to inaccurate interpretations of overlap. For example, Figure 2-16 shows that the home range of bird 6 travels through the core area of bird 7. While it is true that bird 6 used the nearby stream as a foraging corridor, this stream is separated from the observed core area of bird 7 by a hill and a walking trail, which bird 6 was never observed to

have crossed. This circumstance where the home range overlay map incorrectly depicts home ranges of some birds traversing core areas of other birds is common.

By far, birds overlapped most frequently and in highest numbers at the south end of the upper lake, which has been identified as the flock site. Four of the 10 transmittered birds (4, 5, 6 and 8) had core areas that overlapped here. Numerous other pāteke, including females, juveniles and other non-transmittered singles were also frequently observed at the flock site, most notably during flocking season. The highest number of pāteke observed at the flock site at a given time was 11 birds. In addition to the four transmittered birds who held core areas within the flock site, three other transmittered birds (1, 7 and 10) were also observed at the flock site between one and three times. However, as discussed in Section 2.3.3 above, up to 5% of outlying points were discounted for these birds in order to construct realistic home ranges, and so the flock site was not included in their home ranges.

In a broader context, flock sites exist to provide a location in which birds can socialize. It is typically at this site that birds establish dominance over one another and find their mates. Given the frequency and abundance with which the flock site is inhabited, it is clear that a suitable flock site is an essential component of any sustainable pāteke population. This notion is fortified by the dynamics of the pāteke population at Tiritiri Matangi Island, where after several releases, several female pāteke were present but only one male remained at the open sanctuary (Evans, 2015b). This anomaly has been attributed, in part, to the absence of suitable wetlands for flocking and a suitable wetlands flocking location has since been built at the open island sanctuary (Evans, 2015b).

2.5.3 Mortality

Of the 10 transmittered birds, three died during the course of the study. All three birds died in the early spring (September or October). At least two of the birds were very thin at their time of death and are speculated to have died of starvation. Further discussion relating to challenges of procuring sufficient food will be provided in Chapter 4.

2.5.4 Genetic Diversity

Based on the findings of Bowker-Wright et al. (2012), it appears that lack of genetic diversity was already a potentially confounding problem for the 18 founder pāteke at Zealandia. Even assuming that these 18 birds were sufficiently unrelated, the fact that 51.4% of nests with known parentage have been a direct product of inbreeding strongly suggests that this population is in peril. High instance of inbreeding is extremely detrimental to any population and can negatively affect individuals' survival, immunological competence, size, growth rate, viability, normal physiological development and ability to attract a mate (Neaves et al., 2015). Given this, it would not necessarily be logical to attribute shortcomings of this population (i.e., reduced fecundity, failure to thrive, etc.) to what may be considered by some as marginal habitat.

2.5.5 Conclusions and Management Implications

From 1968 through the early 2000s, pāteke releases were a new phenomenon and were largely experimental. Release sites were chosen, in part, based on geographical regions that were inhabited by pāteke prior to human settlement. These landscapes, however, were vastly transformed from pre-human days with regard to predator composition, wetlands availability and quality, food abundance, biodiversity and

species richness, among other things. The success of reintroductions of captive-reared pāteke into novel release sites was unknown. Several early releases, namely those in the Manawatu region and on Matakana Island, illuminated the importance of predator control in pāteke release areas (Dumbell, 2000). Failure to establish self-sustaining populations at other releases including those at Kapiti, Mana and Tiritiri Matangi Islands, was likely due to a combination of factors, including limited carrying capacity, marginal habitat and low numbers of released birds who already lacked genetic diversity. While many early releases were deemed unsuccessful in creating a sustainable population, they have been rightfully praised as providing invaluable insight into the requirements for success of future releases as well as creating public awareness and support of this incredible endemic duck that had, until recent years, been slipping quickly toward extinction.

Pāteke home range attributes have significant implications for management as they relate to the purpose and suitability of potential future release sites. In cases such as Zealandia and several other smaller-scale release sites, where pāteke are released primarily for the purposes of species advocacy, determination of home range size and extent of overlap may play a less important role than in cases where a self-sustaining population is the primary goal. In these cases, release sites containing habitats that require individuals to utilize larger home ranges (i.e., forested habitats) would require that the overall release site be large enough to accommodate such a quantity of birds. This becomes challenging when considering the cost and amount of time and ongoing collaborative labor required to maintain a fenced (or unfenced) predator-controlled environment. In all cases, however, appropriate habitat composition within release sites, and thus within potential home ranges, remains an important consideration.

The Brown Teal Recovery Group defines a population as containing 50 or more pairs of pāteke (K. Evans, pers. comm., 31 Aug. 2016). This number is increased from 10 pairs, as defined in the original pāteke recovery plan (Williams & Dumbell, 1996) and is consistent with the 50 pairs sited in the whio recovery plan (Glaser et al., 2010). This figure, however, is not an exact science and is only suggested as a guideline. When compared with the current population estimate of 40-50 individuals within the fence, Zealandia's pāteke population falls short of the definition of a stable, self-sustaining population. This is not to say, necessarily, that pāteke have reached their carrying capacity at Zealandia, or even that the population is finitely limited to areas within the fence.

While home range analysis has shown that many of the streams and tributaries within Zealandia as well as most real estate along lake edges and neighboring wetlands are already occupied by pāteke, there may still be potential for the valley to accommodate slightly higher numbers of pāteke. It is very unlikely however, that the 225-hectare fenced valley itself would be able to accommodate 50 pairs. Because these bush pāteke have demonstrated that they require between 6.80 and 43.85 hectares in individual home range, and that these home ranges must be comprised of specific habitat features and overlap with one another minimally, a predator-controlled, forested facility that would accommodate large enough numbers of pāteke to sustain a viable population would need to be much larger than a release site dominated by wetlands and tall grasses. This is particularly problematic because low population numbers invariably lead to inbreeding, reduced fertility and population decline over time.

Projects such as the halo project, which implement continuous non-native predator trapping within a large buffer area surrounding Zealandia, provide an increased potential for pāteke and other vulnerable native fauna to exist in the bush outside and adjacent to Zealandia. Some of Zealandia's pāteke have been known to travel outside of the fenced area, and on at least one occasion, have traveled back inside. The degree to which pāteke are able to exist in halo areas, where mammalian predators are reduced in number but are still present, and where the habitat composition and quality is largely unknown but likely of lower quality than Zealandia's, would necessitate further evaluation outside the fence.

Recent pāteke releases in areas where intensive predator control is ongoing, but where the area is not fenced, have yielded mixed but promising results. Pāteke released within Te Henga Wetlands in Bethells in 2015 and 2016 have thus far proven to be adapting well to their unfenced but predator-controlled environment (Forest & Bird, 2016). The habitat consists of over 500 hectares of wetlands, just inland from Bethells Beach, within the Waitakere ranges. Pāteke released along the Arthur River near the Milford Track between 2009 and 2013 had been adapting and surviving well until a recent beech mast led to a predator plague, decimating the pāteke population (ICWT, 2016). This site was dominated by a wide, slow-flowing section of the Arthur River with an abundance of surrounding tall grasses, scrub and adjacent forested tributaries, lying at the foot of snow-capped mountains in the Fiordlands. Relative success of pāteke within unfenced but predator-controlled areas suggests that halo and similar projects are a useful and potentially critical tool for increasing the potential carrying capacities for smaller facilities, such as Zealandia, to support larger populations of threatened species like the brown teal.

Home range analysis of Zealandia's pāteke suggests that long stream corridors are a critical component of bush pāteke home range. Video footage from camera traps suggests that bush pāteke acquire a majority of their food from these streams. Home range analysis was also useful in identifying core areas within pāteke home ranges, which correlate closely with locations used by pāteke for daily roosting. Many of the bush pāteke roost locations bear a striking similarity to one another, despite being located in various locales throughout the sanctuary. Roost locations will be described in greater detail in Chapter 3. The third key component of several bush pāteke home ranges included the flock site, located within the wetlands at the south end of the upper lake. While only four of the 10 transmittered pāteke had core areas that fell within the flock site, numerous non-transmittered birds were also observed here. Further, all but two of the 10 transmittered birds were observed at the flock site at least once over the course of the study, and may have visited the flock site more frequently over the course of the study and in previous years. Based on this study, as well as knowledge of pāteke behavior within other populations, a suitable flock site is a critical component of any release site. Flock site composition will be discussed in greater detail in Chapter 3.

The potential exists that pāteke prefer lake, coastal and similar wetland habitats dominated by open water and abundant tall grasses, but that when these preferred locales are all occupied, excess birds are pushed into potentially marginal "second choice" forested habitat. However, Zealandia's pāteke appear to have adapted well from their captive rearing to their predominantly-forested environs, with forest streams being a key component of both lake and bush pāteke home ranges. While pāteke have historically thrived in these forest settings, current quality of forest habitat is likely subpar to the forest habitat they occupied in a pre-human setting. In

facilities such as Zealandia where monumental efforts are ongoing to restore and maintain native biodiversity, pāteke stand a greater chance of sustaining themselves. Similar to forested habitat degradation, the coastal areas presently occupied by pāteke have also been drastically modified by human inhabitance. Resilience and adaptability of pāteke are highlighted by their continued survival in these population strongholds. Thus, while this study has shown that pāteke do retain the behavioral plasticity to successfully inhabit forested habitat at Zealandia, further studies comparing breeding success, age, and weight of pāteke in open water settings versus forest settings would be more telling of forest habitat suitability, particularly in forests with unknown habitat quality, such as that found within the halo. Future studies should be cognizant of the extent to which their study populations are affected by inbreeding as this could be an underlying factor in differences in overall fitness, unrelated to their habitat.

3 Spatial and Temporal Roosting Patterns

3.1 Introduction

The concept of avian roosting broadly refers to the time a bird spends sleeping or resting. Many bird species have developed specialized roost-related physiological and behavioral adaptations, primarily to enhance defense against predation while sleeping. Passerines, for example, are capable of reflexively clasping their perching substrate to remain perched above ground even in sleep (Brooke & Birkhead, 1991). Many species, including *Anas* species, are capable of unihemispheric slow-wave sleep, which allows one hemisphere of the brain to sleep, while remaining open-eyed and vigilant of potential threats using the opposite hemisphere (Rattenborg, Lima & Amlaner, 1999). Some species rely on the safety of communal roosting behavior, which in some cases, also plays an important role in thermoregulation and foraging efficiency (Beauchamp, 1999).

Most knowledge of pāteke roost behavior and roost habitat preference is based upon what has been observed within the remnant Great Barrier Island and Northland populations. Numerous reports refer to the use of communal roost sites in areas along the edges of tidal marshes and streams. These communal roosts, also referred to as flock sites, are characterized by quiet and slow-flowing tidal waters, an abundance of rushes and sedges, low overhanging vegetation, undercut stream banks and adjacent escape cover (Dumbell, 1986 & Ogle, 1981).

While many species rely on communal roosting for protection from predation, thermoregulation and foraging efficiency, it is widely accepted that pāteke roost communally for the primary purpose of forming and/or strengthening pair bonds. Most accounts suggest that pāteke roost within these communal roosts in greatest

numbers during flocking season from November through May (McKenzie, 1971; Wilson, 1959; Reed, 1972; Bell, 1976; Williams, 1977; Ogle, 1980; Ogle, 1981, as cited in Dumbell, 1986). Between May and November, it is reported that the breeding component of the population retreat to various discrete breeding territories nearby the communal roost (Dumbell, 1986). A smaller non-breeding component of the population, generally comprised of single males and juveniles, remains at the communal roost site year-round (Belle & Braithwaite, 1964; Weller, 1975, as cited in Dumbell, 1986).

Many of these earlier studies of pāteke were limited in their means of collecting observations in several ways. Some accounts of roosting behavior, while shedding light on types of habitat used and group interactions, were based on observations made over a very short period of time. Earlier studies were also technologically limited, without access to camera traps or telemetry. Moreover, studies that did make use of telemetry often fitted transmitters only to birds which were found at the communal roosts, effectively eliminating the opportunity to study behavior of teal roosting primarily in the forest.

As discussed previously, this study fitted transmitters to birds found on the lakes as well as birds found far upstream of the lakes in an attempt to determine any differences in behavior between the two, and to ensure that behavior of bush-dwelling bird was evaluated. This chapter will identify the areas in which pāteke prefer to roost at Zealandia as well as the extent to which individual core roost locations overlap with one another. A detailed characterization for each preferred roost site will be provided. Individual average roosting distance from the nearest lake will be calculated for each bird. Temporal roost patterns will be evaluated via a month-by-month breakdown of

average roost site distance to the nearest lake as well as through a chronological fix-by-fix evaluation of individual roost distances to the lake.

3.2 Objectives

This part of the study aims to identify roosting patterns of pāteke at Zealandia through the use of telemetry. It is hypothesized that pāteke will consistently roost in one or a few locations, thus spending most of their roosting time within core areas of their individual home ranges. It is also hypothesized that roost locations for forest dwellers will vary seasonally, in relation to flocking season.

3.3 Material and methods

3.3.1 Banding and transmitter fitting

As discussed in Chapter 2, 10 pāteke were captured and fitted with color and metal identification bands as well as transmitters between November 2013 and October 2014. This study used Holohil RI-2B transmitters with a minimal 12-month battery life. Transmitters weighed 11 grams and were fitted to birds using a backpack harness mount with built-in linen weak-link thread, in accordance with the requirements and procedures set forth in the DOC SOP for attaching radio and data-storage tags to birds (DOC, 2011).

One of the 10 transmittered birds was hand-netted at WBRC and released along a forested stream within Zealandia. The remaining nine were captured at Zealandia. Seven transmitters were fitted to birds known to utilize forested habitat (this includes the one wild bird transferred from WBRC and released in forested habitat). The remaining three transmittered pāteke are individuals who, prior to transmitter fitting, were observed to remain in specific locations along the lake edges.

Birds at Zealandia were captured using one of two methods. One lake bird was hand-fed and then hand-netted. The remaining eight study birds were keyed in to stationary feeders containing maize grits, which were positioned inside 1-meter x 1-meter x 2-meter wire mesh cages. Cages with feeders were placed along streams within the forested portions of Zealandia at six different locations, to ensure that the birds captured and fitted with transmitters were birds known to occupy forested habitat. The remaining three locations in which birds were captured and fitted with transmitters were along the edges of the upper and lower lakes. Refer to Figure 2-1 in Chapter 2 for a map depicting the capture location of each of the transmittered birds.

3.3.2 Use of telemetry to identify spatial and temporal roosting patterns

All tracking was done by foot using a Telonics TR4 receiver and handheld portable Yagi aerial antenna. As elaborated upon in Section 2.3.2, bird location points were collected using the homing in method. Daytime tracking was carried out at a minimum of five days per week in order to identify individual roost locations on a continual basis. However, individuals who occupied more obscure locations and/or relocated their roost sites frequently, resulted in having fewer daytime observations. For all daytime tracking sessions, an initial comprehensive scan was undertaken at the top dam to determine presence/absence of all 10 birds at the flock site, or "communal roost", located at the south end of the top dam.

3.3.3 Statistical methodology

Analysis of individual core roost areas was conducted using the kernel utilization distribution (KUD) (Worton, 1989) method within the adehabitatHR package (Calenge, 2015) in R Studio Version 3.3.1 (R Core Team, 2016). Polygons created in R were subsequently imported into QGIS Wien 2.8.7 and overlaid on Google Maps

satellite imagery (QGIS, 2009). All analyses use only telemetry observations that were accurate to within 50 meters or less of the bird's actual location. Any observations at the beginning or end of the study that may have been influenced by placement of feeders were omitted to ensure that the findings reflect the birds' natural and unaltered behavior.

In analyzing habitat use, core areas of use are most commonly assessed using 50% isopleths. Thus, core roost areas for each bird were calculated using the 50% KUD method. While the minimum convex polygon (MCP) method provided useful insight into pāteke home range characteristics, this method does not allow for the identification of multiple areas of concentrated activity and so, was not used in the core roost analysis.

The KUD method is based on the concept of probability density estimation and thus creates an output with a three dimensional construct, which can be depicted in layers (isopleths) using varying probabilities. Calculation of the probability distribution (formation of the kernel[s]) is based on the distance of each point from the others (i.e., the concentration of points within the latitudinal/longitudinal plane). Calculation of kernel density estimates also incorporates the use of bandwidth, which is a free parameter that applies buffers (bands) around each kernel of concentrated activity. The width of these bands can be widened or narrowed by changing the bandwidth input, thus drastically affecting the size of the KUD output.

Several methods exist for selecting the most appropriate bandwidth to fit a given data set. My analysis uses the bandwidth selection method suggested by Kie et al. (2010), wherein a bandwidth is selected for each data set *a priori*, which produces the smallest home range polygon that still comprises a single polygon at 95%. Even when

a dataset-specific bandwidth is carefully selected through trial and error, there are still several occasions where the smallest-single-polygon output can drastically overestimate the actual home range of the animal, particularly in instances where large data voids exist between two kernels of concentrated activity. In these cases, additional modifications must be made in order to produce the most realistic output. Bandwidth selection and modifications are discussed in greater detail in Section 2.3.3.

As pāteke roost during the day, only daytime telemetry fixes were used to assess roosting behavior. With the exception of one lake bird (bird 3), core roost areas were calculated for each bird using the same bandwidth that was selected for their home range data sets, which included both day and night telemetry fixes. For these nine birds, night telemetry fixes were predominantly located between or proximate to the kernels of concentrated activity. The kernels were generally comprised of daytime telemetry fixes. Therefore, the previously-used home range bandwidths were suitable. In the case of lake bird 3, however, day telemetry fixes were fairly close together, while night telemetry fixes were predominantly located further north. Thus, for this individual, a bandwidth was selected which produced the smallest single polygon using only daytime telemetry fixes.

As with calculating kernel density estimates for overall home ranges, the same far outlying points that significantly affected the output of home ranges were removed for birds 1, 6, 7, 9 and 10 when calculating their core roost areas. Again, the number of outlying points removed for any bird did not exceed 5% of the total number of fixes collected for that individual.

Survey bias during telemetry data collection caused observations at more easily-accessed locations (i.e., the flock site at the south end of the upper dam) to be over-

represented for birds 4, 5, 6 and 8. As discussed in greater depth in Section 2.3.3, proportions of daytime flock site observations to total daytime observations (whether or not they were accurate to within 50 meters) were calculated for these four birds in order to determine what percentage of daytime flock site fixes must be discounted to portray an accurate representation of the birds' daytime locations. "Blank" observations were recorded for birds determined not to be within the flock site, but whose precise location was not confirmed. The following equation was used to calculate the appropriate number of flock site observations (y) to discount from the overall dataset for the purposes of calculating and plotting KUD core roost areas:

$$100 \times \frac{\text{flock site fixes}}{\text{flock site + bush fixes}} = \text{A\%}$$

$$100 \times \frac{\text{flock site fixes}}{\text{flock site + blank + bush fixes}} = \text{B\%}$$

$$100 \times \frac{\text{x}}{\text{flock site + bush fixes}} = \text{B\%}$$

$$\text{flock site fixes - x = y}$$

The core roost area sizes did not meet the parametric assumption of variance homogeneity, so a Wilcoxon rank-sum test was used to determine difference between lake pāteke and bush pāteke core roost area sizes. Temporarily disregarding the pre-ordained categories of "bush pāteke " and "lake pāteke ", a Wilcoxon rank-sum test was also used to determine difference between core roost area sizes of pāteke maintaining core roost areas exclusively adjacent to standing water (birds 1, 2, 3, 4 and 7) and those with core roost areas in the bush (5, 6, 8, 9 and 10).

Core roost area overlap was calculated using 50% KUD core roost areas. Overlap was calculated using the following equation described by Poole (1995):

$$100 \ \times \ \frac{2 \times \text{area of overlap}}{\text{home range of animal A} + \text{home range of animal B}}$$

The mean distance of individual roost sites to the nearest lake was calculated for each bird for every daytime telemetry observation that was accurate to within 50 meters. Data were adjusted to account for survey bias which led to increased observation at the flock site prior to calculation of mean roost distance. The mean error of these daytime telemetry fixes was also calculated for each bird.

The mean distances of roost locations from lakes did not meet the parametric assumption of variance homogeneity, so a Wilcoxon rank-sum test was used to determine difference between lake pāteke and bush pāteke average roost-to-lake distance.

A month-by-month breakdown of the proportion of daytime flock site roost fixes to overall daytime roost fixes was calculated for each bush pāteke as well as cumulatively for all bush pāteke to identify any potential seasonal preference to roost at the flock site.

3.4   Results

3.4.1   Core Roost Area Size

Prior to KUD analysis, daytime data were adjusted to account for survey bias at the flock site for birds 4, 5, 6 and 8 (Table 3-1).

Table 3-1. Breakdown of flock site, bush, and "blank" telemetry fixes for birds 4, 5, 6 and 8.

Bird ID	Flock Site Fixes	Bush Fixes	Total Fixes	% Fixes at Flock Site	Blank Bush Fixes	Bush + Blank Fixes	Total Fixes	Adjusted % Fixes at Flock Site
4	109	15	124	87.90%	9	24	133	81.95%
5	75	23	98	76.53%	42	65	140	53.57%
6	45	44	89	51%	74	118	163	27.61%
8	16	36	52	30.77%	105	141	157	10.19%

I calculated overall core roost area sizes and individual core polygon sizes for 10 pāteke who had between 29 and 196 total daytime telemetry fixes. Mean and standard deviation were calculated for lake pāteke and bush pāteke core roost areas (Table 3-2). Core roost areas tended to be slightly larger for bush pāteke than for lake pāteke (Figure 3-1).

Table 3-2. Mean and standard deviation (SD) for 50% KUD core roost area sizes for lake pāteke (1 – 3) and bush pāteke (4 – 10) in hectares.

Bird ID	Polygon 1	Polygon 2	Polygon 3	Polygon 4	Total
1	1.212	0.151	0.001	x	1.364
2	0.115	0.072	x	x	0.187
3	0.138	0.103	x	x	0.241
Mean					0.597
SD					0.664
4	0.836	x	x	x	0.836
5	2.626	0.043	x	x	2.669
6	2.971	2.788	x	x	5.759
7	0.883	x	x	x	0.883
8	2.117	1.572	1.062	0.432	5.183
9	0.853	x	x	x	0.853
10	4.170	1.613	0.859	x	6.642
Mean					3.261
SD					2.551
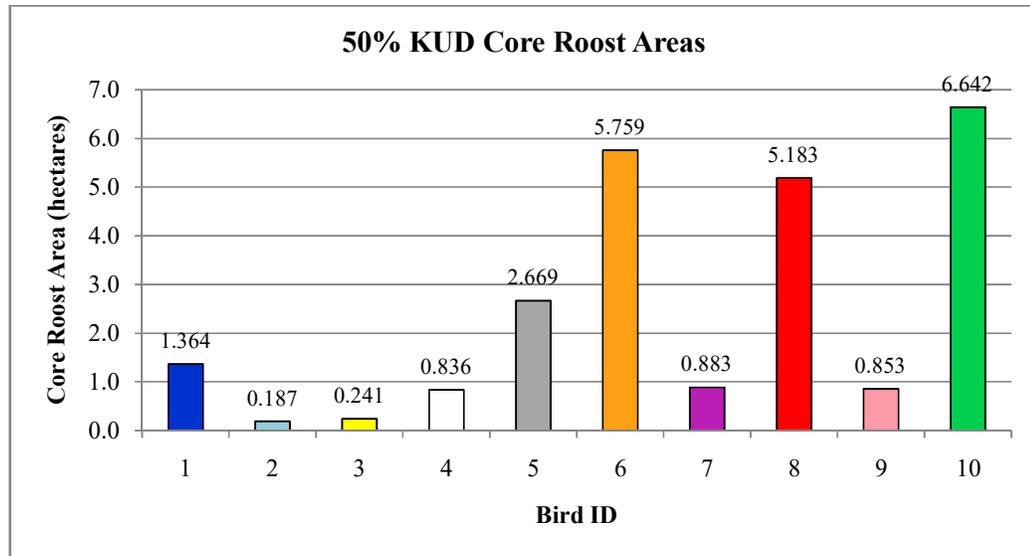
Figure 3-1. 50% KUD core roost area sizes for lake pāteke (1-3) and bush pāteke (4-10) in hectares.

Using the KUD method, lake pāteke had a mean core roost area of 0.597 ha (SD = 0.664) and bush pāteke had a mean core roost area of 3.261 ha (SD = 2.551). Maps depicting 50% KUD core roost areas as well as daytime telemetry observation points for all 10 birds are included in the pages below (Figure 3-2 through Figure 3-6). The 50% KUD core roost areas of lake pāteke were not significantly smaller than that of bush pāteke (P = 0.117).

The 50% KUD core roost areas of pāteke who maintained core roost areas exclusively adjacent standing water were significantly smaller than that of pāteke with core roost areas in the bush (P = 0.032).

Figure 3-2. 50% kernel utility distribution core roost area contours (Bird 1 above, Bird 2 below).

Legend – Bird 3 (YMunb)

○ Daytime Observation
50% KUD (total area = 0.241 ha)
Polygon 1 = 0.138 ha
Polygon 2 = 0.103 ha

Legend – Bird 4 (WK-M)

○ Daytime Observation
50% KUD (total area = 0.836 ha)
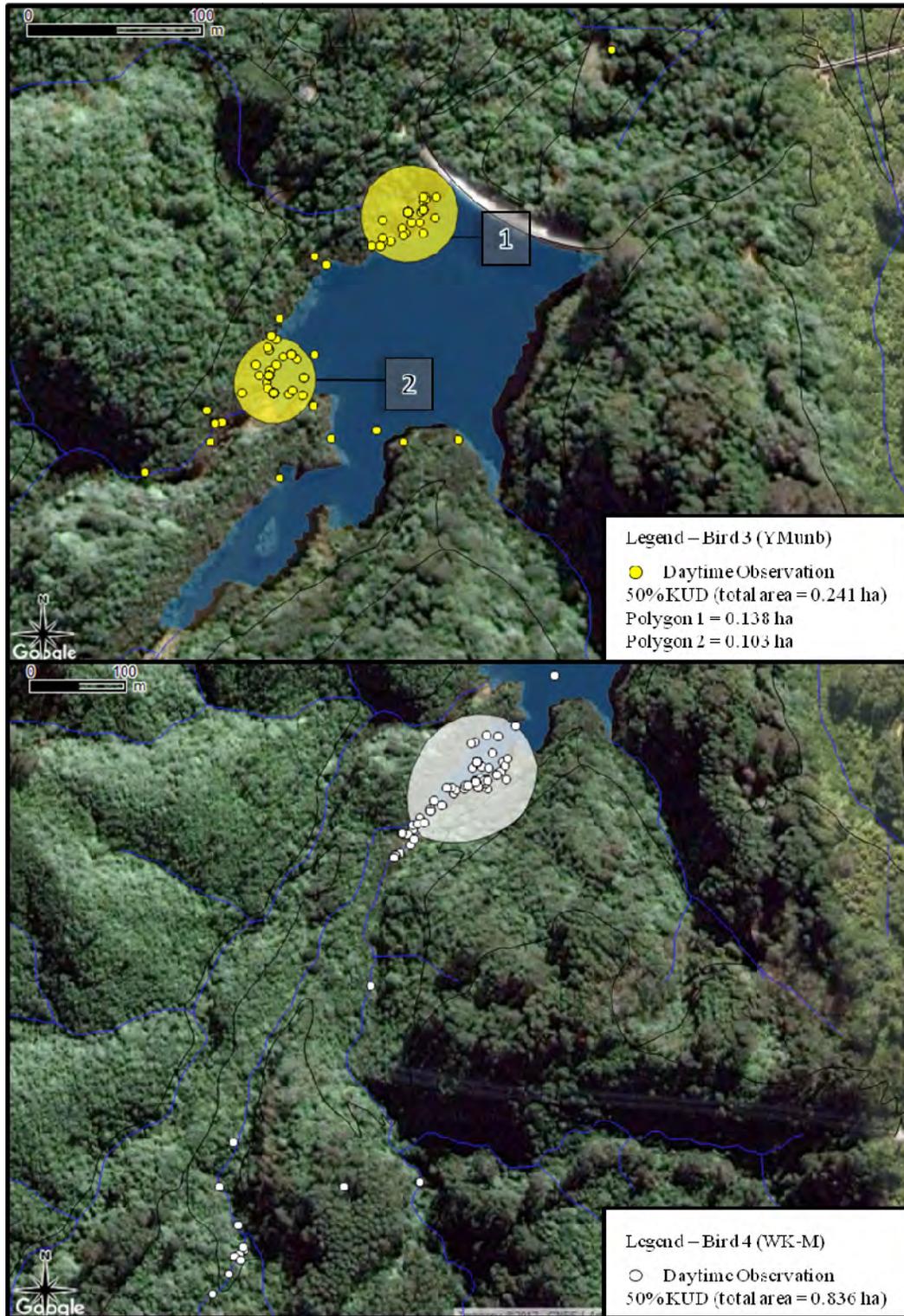
Figure 3-3. 50% kernel utility distribution core roost area contours (Bird 3 above, Bird 4 below).
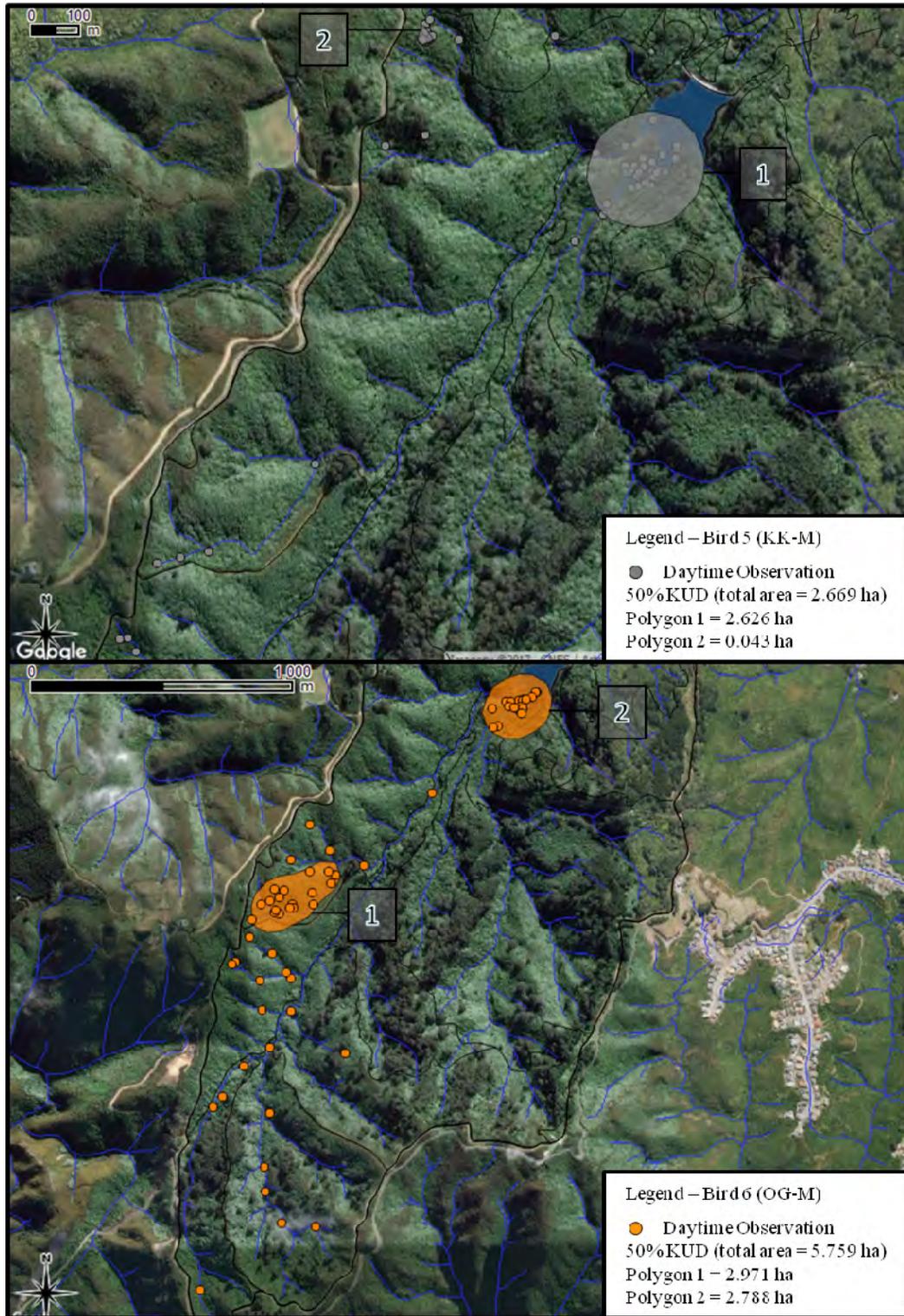
Figure 3-4. 50% kernel utility distribution core roost area contours (Bird 5 above, Bird 6 below).
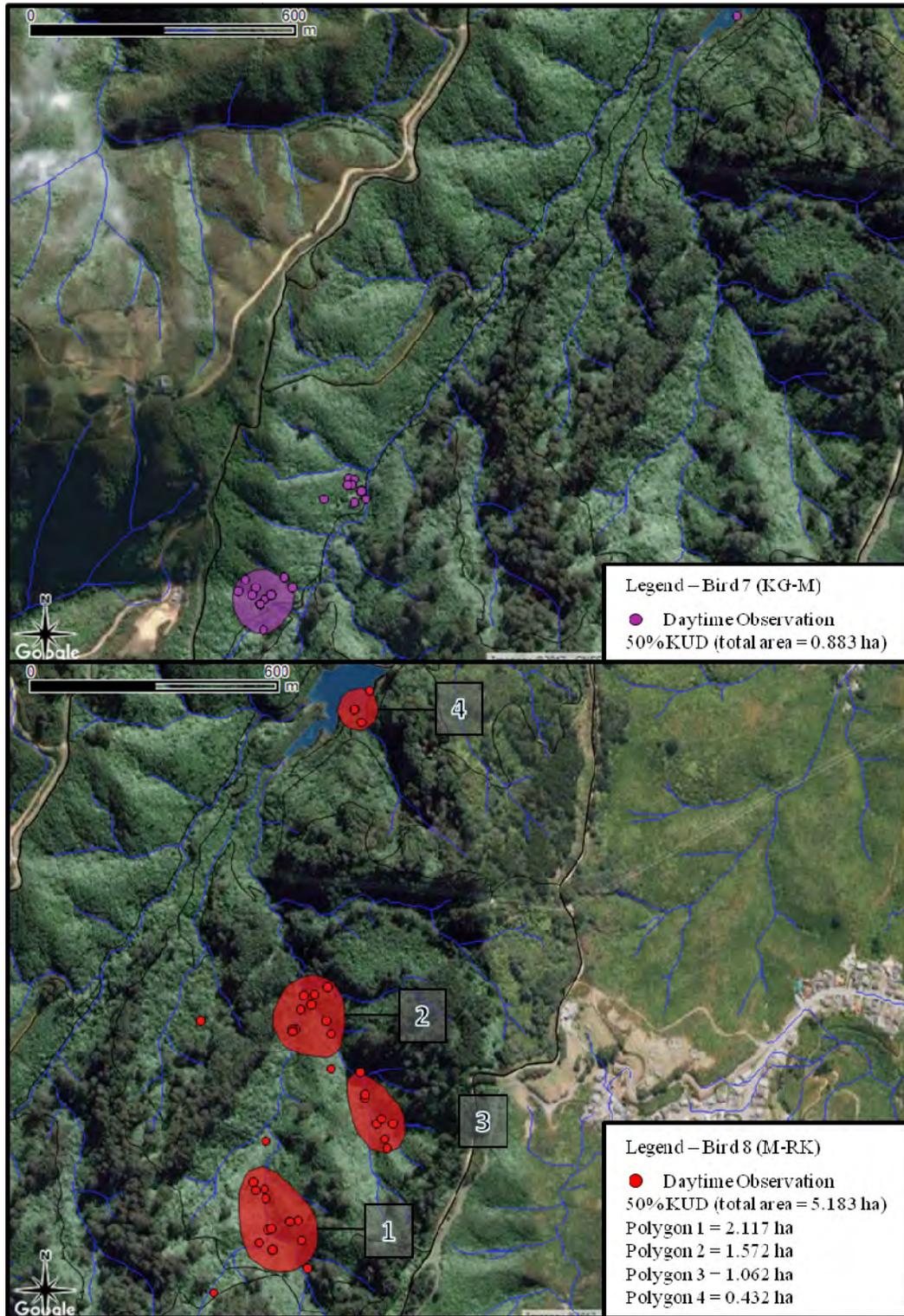
Figure 3-5. 50% kernel utility distribution core roost area contours (Bird 7 above, Bird 8 below).

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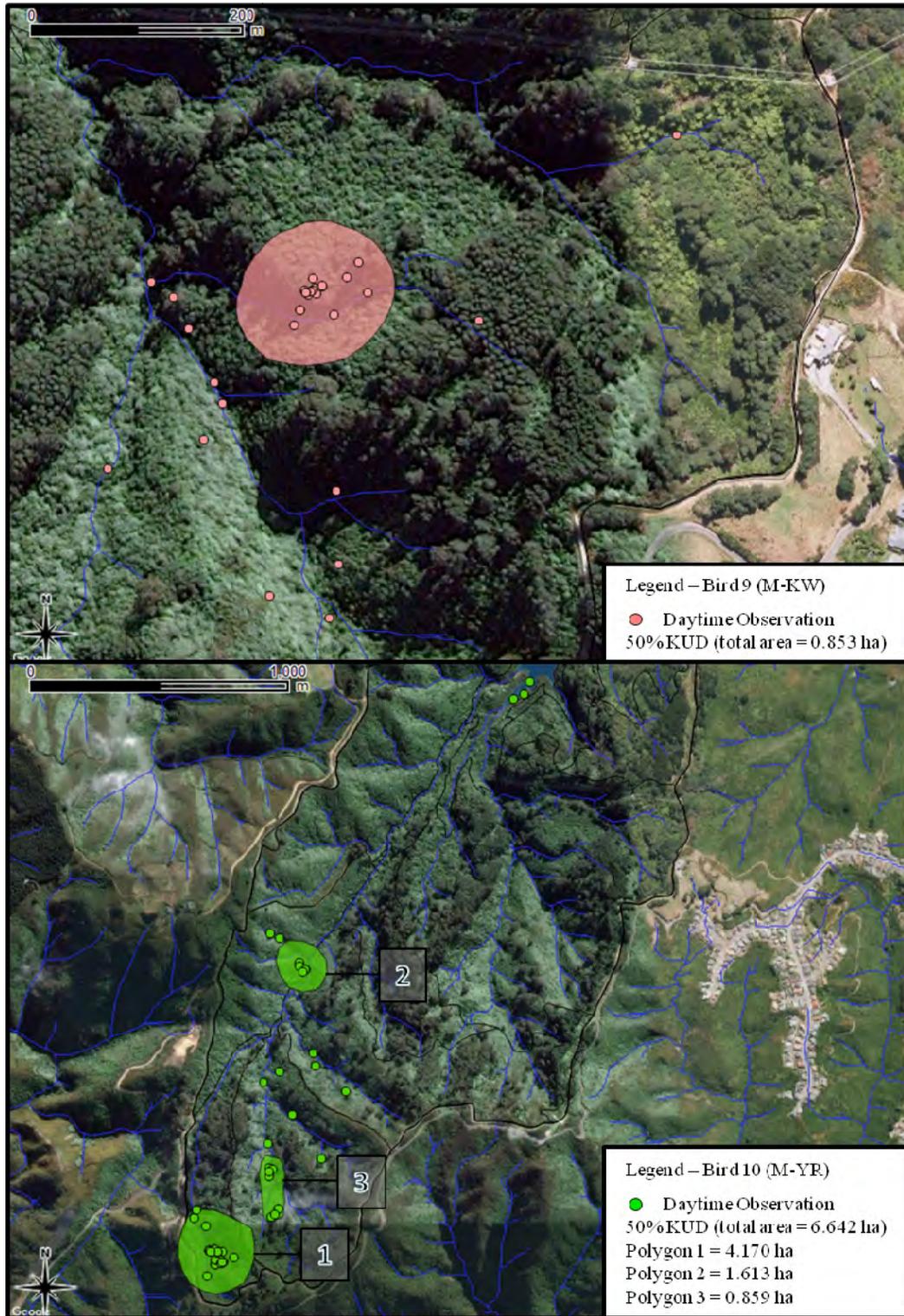
Figure 3-6. 50% kernel utility distribution core roost area contours (Bird 9 above, Bird 10 below).

3.4.2 Core Roost Area Overlap

Core roost area overlap between the 10 transmittered birds occurred almost exclusively within the flock site at the south end of the upper lake. The only other instances in which core roost areas were observed to overlap consisted of a 0.6% overlap between bird 8 and bird 9, which was likely attributable to oversmoothing of the KUD output, and not to an actual shared core roost area (Table 3-3). The second instance of reported overlap was of lake bird 3 overlapping with the flock site roosts of bird 5 and bird 6, which are also not believed to be representative of true overlap. Locations in which each core roost area overlapped are shown below (Figure 3-7).

Table 3-3. Extent of 50% KUD core roost area overlap between study birds.

	1	2	3	4	5	6	7	8	9	10
1	x	x	x	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x	x	x	x
3	x	x	x	x	7.08%	3.43%	x	x	x	x
4	x	x	x	x	47.70%	25.35%	x	x	x	x
5	x	x	7.08%	47.70%	x	60.99%	x	5.92%	x	x
6	x	x	3.43%	25.35%	60.99%	x	x	4.62%	x	x
7	x	x	x	x	x	x	x	x	x	x
8	x	x	x	x	5.92%	4.62%	x	x	0.60%	x
9	x	x	x	x	x	x	x	0.60%	x	x
10	x	x	x	x	x	x	x	x	x	x
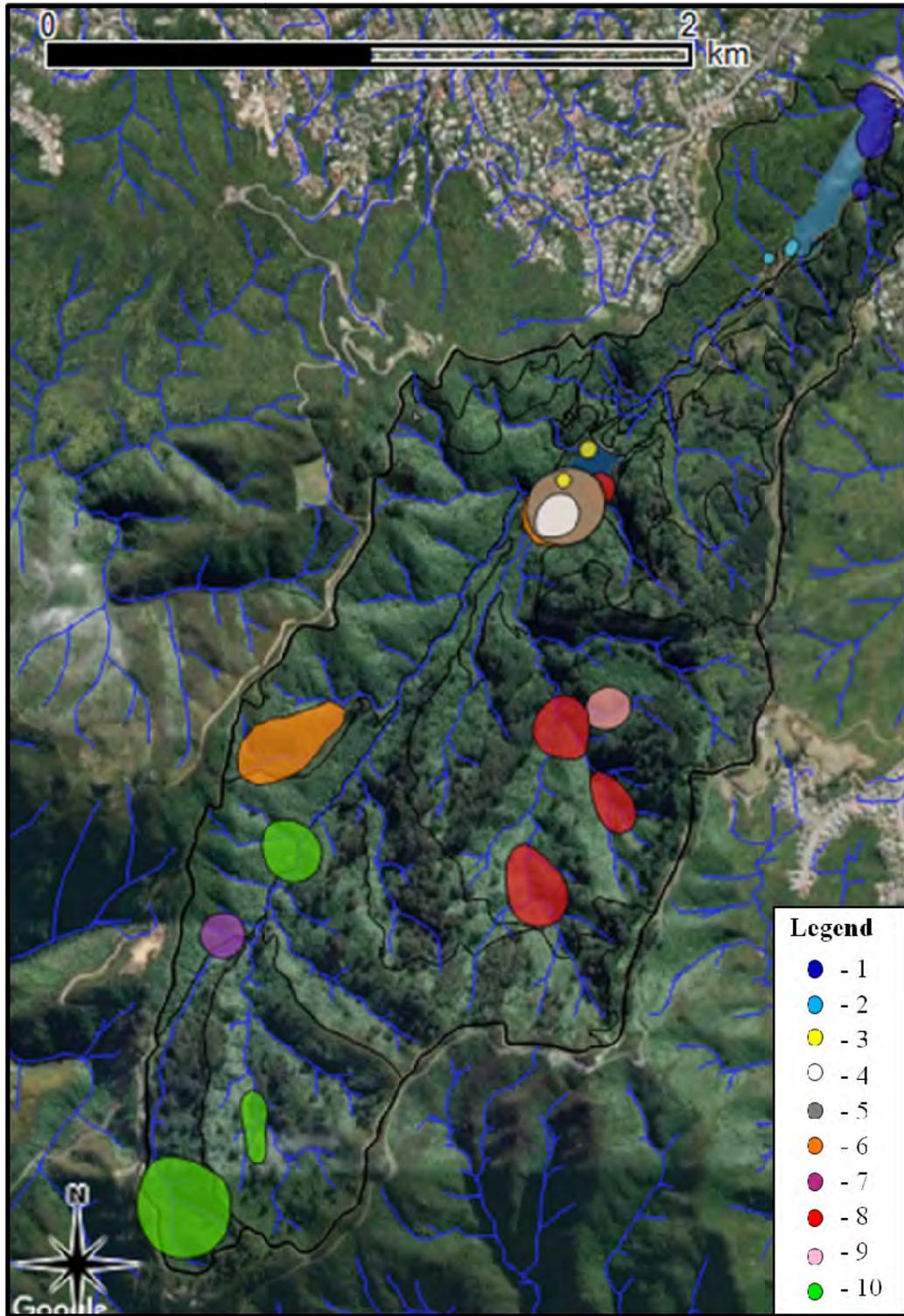
Figure 3-7. KUD core roost areas for all 10 study birds, showing extent and locations of overlap.

3.4.3   Preferred Roost Site Characteristics

Use of telemetry identified 16 preferred roost sites, which are specific locations to which pāteke were tracked within close accuracy and on numerous occasions. Seven preferred roost sites were located along a lake edge and nine were located within the bush. Preferred roost sites were identified as such towards the end of field data collection for the purposes of enabling detailed characterization of the specific areas in which pāteke were frequently found roosting. The locations of these sites correlate closely with the core roost areas identified using the 50% KUD analysis for daytime telemetry fixes. Locations of each of the identified preferred roost sites are shown in Figure 3-8.
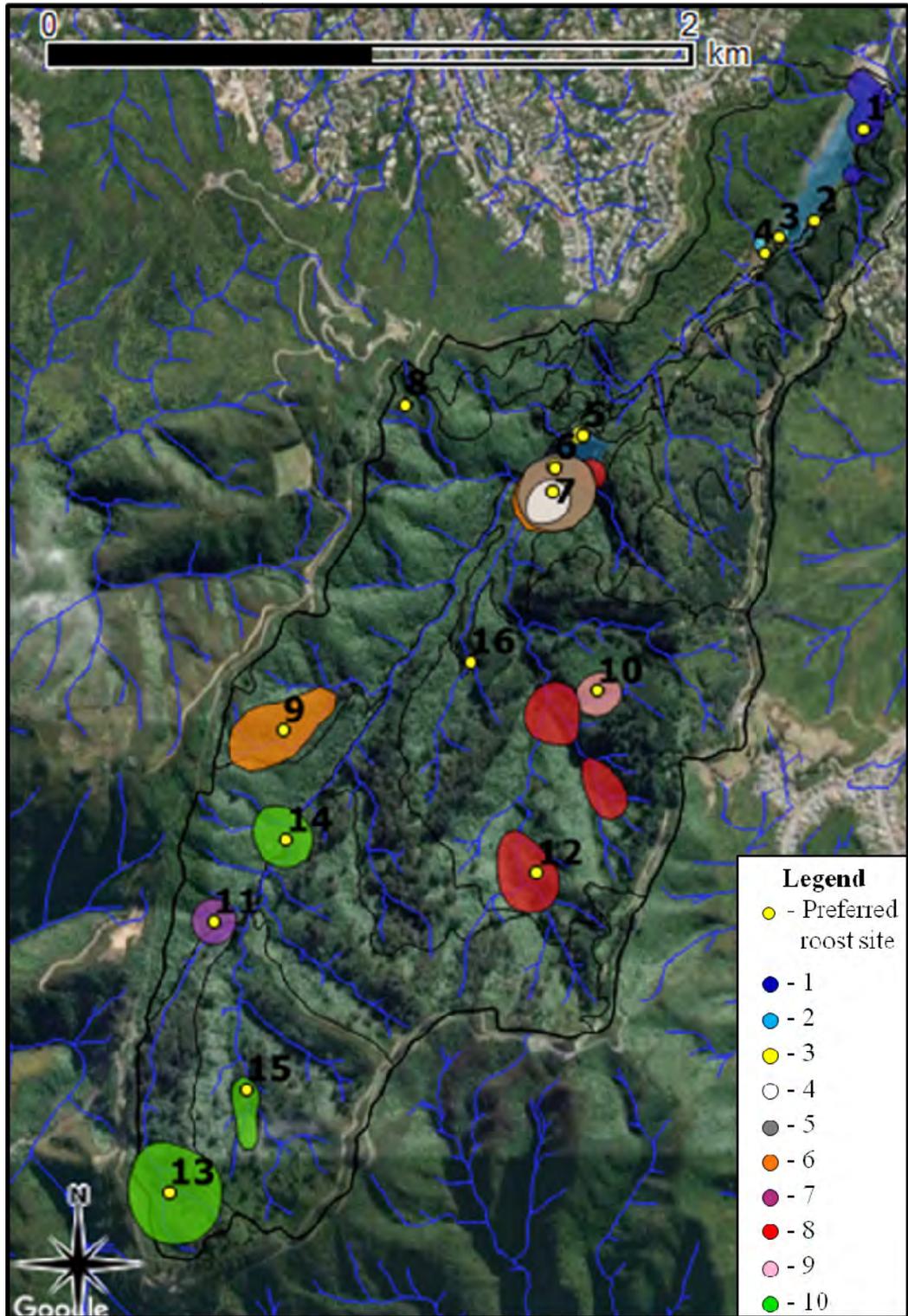
Figure 3-8. Preferred roost sites and KUD core roost areas for all 10 study birds.

The following is a description of the physical attributes and general vegetative composition of each identified preferred roost site.

SITE 1

This roost site is located on the eastern edge of the lower dam at its north end. The site is fairly steep with a slope of approximately 45 degrees. The ground consists primarily of leaf litter and a near-monoculture of hounds tongue (*Microsorum pustulatum*) as the ground cover. Closer to the lake edge, the ground becomes more pebbly with small patches of exposed rock, which continue down-slope into the water. The understory is fairly open, containing mostly hangehange (*Geniostoma rupestre*), mapou (*Myrsine australis*) and rangiora (*Brachyglottis repanda*), and to a lesser extent shining spleenwort (*Asplenium oblongifolium*), rewarewa (*Knightia excelsa*), common broom (*Cytisus scoparius*) and kawakawa (*Macropiper excelsum*). The maximum canopy height at this location is four to five meters. Canopy trees include kanono (*Coprosma grandifolia*), mahoe (*Melicytus ramiflorus*) and putaputaweta (*Carpodetus serratus*). The water's edge is densely vegetated, particularly with tutu (*Coriaria arborea*), and overhangs the water by two to three meters.

SITE 2

This roost site is located on the eastern edge of the lower dam at its south end. The popular roost location consists of a narrow patch of open ground at the water's edge, which is tucked behind a large fallen tree. The hill rising behind the roost is very steep with a slope of approximately 75 degrees. The ground consists of loose, dry soil and rocks with minimal leaf litter. Vegetation overhangs the water's edge by up to two meters in places. The maximum canopy height is four meters and generally ranges from exposed groundcover and becomes taller further from the water. The ground

cover and understory are very dense and are dominated by blackberry (*Rubus fruticosus*) as well as several other species, including *C. scoparius*, unknown broom (*Genista sp.*) black nightshade (*Solanum nigrum*), narrow-leaved plantain (*Plantago lanceolata*), *M. australis*, makomako (*Aristotelia serrata*) and bracken fern (*Pteridium esculentum*). Moving further back from the water's edge, the understory becomes more dominated by *G. rupestre*, *M. excelsum* and *B. repanda*. Canopy trees include *C. grandifolia*, *B. repanda* and pigeonwood (*Hedycarya arborea*).

SITE 3

This roost site is located at the southwest corner of the lower dam within manmade wetlands. The lake in this location is very shallow and periodically without standing water during prolonged periods of little to no rainfall. Substrate beneath the water here is muddy and hosts a variety of herbaceous plants during dry periods, particularly summer. Six manmade "floating islands" are located close to shore, each roughly 5 meters in diameter. The floating islands are very densely vegetated and are a preferred hiding location for pāteke. Islands consist of mamaku (*Cyathea medullaris*), blechnum fern (*Blechnum novae-zelandiae*), carex grasses (*Carex spp*), harakeke (*Phormium tenax*), wharariki (*Phormium cookianum*), *R. fruticosus*, several species of hebe (*Hebe spp*), *C. scoparius* and five-fingers (*Pseudopanax arboreus*). The site is adjoined to the north by open water. A hill containing dense vegetation rises to the west with a slope of roughly 20 to 30 degrees. The southernmost boundary of the lake, and roost site, is bordered by a four-meter-wide buffer dominated by various tall grasses, including raupo (*Typha muelleri*), toetoe (*Austroderia sp*) and *Carex spp*. Other plants within this buffer include those plants found on the floating islands, as well as karamu (*Coprosma robusta*), taupata (*Coprosma repens*), great bindweed

(*Calystegia silvatica*), tauhinu (*Ozothamnus leptophylla*), *P. lanceolata* and New Zealand cabbage tree (*Cordyline australis*). Beyond this buffer, the roost location is separated from additional manmade wetlands by a 13-meter-wide stretch of maintained lawn.

SITE 4

This roost site is located within manmade wetlands beginning roughly 20 meters south of the lower lake and separated from same by a narrow stretch of maintained lawn and tall grass buffers. The wetlands are approximately 30 meters wide by 50 meters long and up to two meters deep in spots. Substrate is very muddy with patches of submerged aquatic vegetation. These wetlands are open and are scattered primarily with *Austroderia sp* as well as *P. tenax*, *P. cookianum*, *Carex spp* and various other genera of grasses. The wetlands are fed by streams from the south and west and drain into the lower lake. A hill containing dense vegetation rises to the west with a slope of roughly 20 to 30 degrees. A walking trail follows the length of the wetlands and beyond along its eastern perimeter. Small downed trees are found on the western perimeter of the wetlands and are favorite roosting locations. Vegetation immediately surrounding the wetlands includes the aforementioned grasses as well as *Hebe spp*, *C. repens*, *C. robusta*, *C. scoparius*, *R. fruticosus*, *C. silvatica*, *P. lanceolata*, *M. australi*), *K. excelsa*, *C. arborea*, *M. pustulatum*, *B. repanda*, pate (*Schefflera digitata*), *M. excelsum*, *C. medullaris* and *C. australis*.

SITE 5

This roost site is located at the northwest corner of the upper lake. The site lies adjacent a manmade lake approximately 90 meters wide by 120 meters long and is bounded to the north by a large concrete dam. The lake is approximately three meters

deep at its deepest point and the substrate is muddy with an abundance of submerged aquatic vegetation. The first four meters of shore extending back from the lake have no canopy and are overgrown with extremely dense groundcover. Groundcover plants include predominately cutty grass (*Carex geminata*) and *B. novae-zelandiae* as well as herb robert (*Geranium robertianum*), *S. nigrum*, hedge woundwort (*Stachys sylvatica*), *R. fruticosus*, *P. tenax*, *C. scoparius*, gorse (*Ulex europaeus*) and catgrass (*Dactylis glomerata*). Slightly further back from the shore, the canopy extends to approximately four to six meters. Canopy trees include *B. repanda*, *C. robusta*, *C. grandifolia*, *C. australis*, *P. arboreus*, *C. arborea* and *C. medullaris*.

SITE 6

This roost site is located at the southwest corner of the 90-by-120-meter dammed upper lake. The lake is fed by four streams at its south end and one at its northwest corner, and drains northward through a controlled drainpipe. The main features of this roost location include a flat gravel bank roughly nine meters by four meters, which slopes very gradually down into the lake to the north, and is abutted to the south by a dense near-monoculture of *C. geminata*. The westernmost of the four southern streams weaves through beneath the *C. geminata* and drains into the lake on the east side of the gravel bank. Minimal groundcover is found on this open bank, and includes poroporo (*Solanum laciniatum*) velvety nightshade (*Solanum chenopodioides*), scotch thistle (*Cirsium vulgare*), purple foxglove (*Digitalis purpurea*) and *C. repens*. The west bank of the lake within the roost site is lined with thick patches of overhanging tussock grasses and *B. novae-zelandiae*. Vegetation overgrowing either side of the cutty grass monoculture includes various hebes, *C. arborea*, *C. robusta*, *P. arboreus*, *S. digitata* and *M. australis*.

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SITE 7

This roost site is broadly defined as the area encompassing a cove with a small island, dense grass growth and densely-vegetated banks at the southernmost portion of the upper lake. This roost site is also identified as the seasonal flock site. Water within this cove extends northeast from the shore and two stream mouths, approximately 110 meters, where it opens up into the upper lake. The cove is approximately 25 meters wide. The island within the cove is approximately 20 meters long by seven meters wide and has steep rocky shores and extremely thick, impenetrable vegetation perfect for hiding in. A monoculture of *C. geminata* extends south from the cove along the two stream banks for approximately 40 meters. The *C. geminata* patch is roughly 15 meters wide, one to two meters in height, and hides the stream and uneven ground entirely, providing ideal hiding space for teal. The bank along the west side of the cove has a fairly open understory, containing *M. excelsum*, *A. oblongifolium*, *M. pustulatum*, lancewood (*Pseudopanax ferox*), *G. rupestre*, *M. australis* and several species of hebe. The canopy on the west bank is approximately four to six meters tall and includes such tree species as *P. arboreus*, *C. australis*, lemonwood (*Pittosporum eugenioides*), *C. granifolia*, *C. robusta*, kanuka (*Kunzea ericoides*) and *C. arborea*. A walking trail with viewing hides follows along the east bank of the cove, approximately 15 meters from the shore. Vegetation between the trail and shore is low and dense, in most areas only one meter tall. This area consists predominantly of *B. novae-zelandiae*, *P. tenax*, *P. cookianum* and various tussock grasses. The open to semi-shaded areas surrounding this cove also contain hen and chickens fern (*Asplenium bulbiferum*), *O. leptophyllus*, Vietnamese mint (*Persicaria odorata*), *C. scoparius*, puha (*Sonchus oleraceus*), pigfern (*Hypolepis ambigua*), *Austroderia sp*,

D. purpurea, kōwhitiwhiti (*Nasturtium officinale*), tree fuchsia (*Fuchsia excorticata*) and *S. sylvatica*.

SITE 8

This roost site is located within a dense stand of Darwin's barberry (*Berberis darwinii*), near the top of a steep hillside on the west side of the valley. The hillside steepness varies in places and has a maximum slope of approximately 75 degrees in places. The nearest stream is located 35 meters northeast and is surrounded in that area by damp ground with standing water and plant species typical of shaded understory wetlands. The understory at the roost site is extremely dense in spots and is dominated by *M. pustulatum* and *B. darwinii*. Understory also includes hook grass (*Uncinia uncinata*), *B. repanda*, *M. australis*, *P. cookianum*, *B. novae-zelandiae* and *G. rupestre*. The canopy here is approximately three to four meters tall and has wide gaps in places. Canopy species include *B. darwinii*, *P. arboreus* and *M. ramiflorus*.

SITE 9

The individuals utilizing this roost area were recorded at numerous locations along the hillside northwest of the Western Firebreak stream, primarily within the 50-meter stretch between transects J and JK. All sites were within 60 meters of the stream. Generally, the bush east of the stream has a tall canopy, gently sloped topography and a very thin, open understory. West of the stream however, the slope becomes steeper and the understory becomes denser. Within this denser bush are numerous patches, where canopy gaps give way to small stands of nearly impenetrable understory growth. It is within these patches that these individuals chose to roost. One such patch is described here.

This roost site is located on the hillside 30 meters northwest of the Western Firebreak stream on a slope of approximately 45 degrees. The ground here is damp and covered with leaf litter and dead blechnum fern fronds. Numerous fallen branches also make passage difficult. The understory is almost entirely comprised of *B. novae-zelandiae*. Young trees are densely distributed within this four-by-five meter fern patch. These trees are between two and four meters tall and are predominantly *P. arboreus* and *B. repanda*. *M. Ramiflorus* and *G. rupestre* are also very common. Several *B. darwinii* and *M. australis* were also observed.

SITE 10

This roost site is situated along the edge of a flat patch of forest, where the hill drops drastically down to the stream below at a slope of approximately 70 degrees. The stream is located approximately 27 meters south of the roost site. This roost site is located within a stand of roughly 100-year-old radiata pine trees (*Pinus radiata*). The ground is covered with a thick layer of pine needles. The understory of the elevated flat area is quite open and is dominated by *M. pustulatum*. However, vegetation quickly becomes extremely dense at the point where the hill drops off steeply, and where the bird prefers to roost. Dominant understory plants at the roost site include *M. pustulatum* and *A. oblongifolium*, as well as kowharawhara (*Astelia solandri*), *M. australis*, *B. repanda*, *B. novae-zelandiae*, *B. darwinii*, *G. rupestre* and numerous *P. Arboreus* saplings. Also found along the hillside are numerous *C. medullaris* and other small trees including *C. robusta*, *C. grandifolia* and *M. ramiflorus*.

SITE 11

This roost site is situated at the south end of a small patch of wetlands approximately 36 meters from the nearest stream and 1,223 meters southwest of the nearest lake. The

wetlands contain an area of permanent standing water approximately 20 meters long by 10 meters wide and less than one meter deep at its deepest. The substrate consists of deep mud and leaf litter. There is an abundance of emergent plants throughout. Within most of the roost site, the ground is muddy and uneven, containing pockets and puddles. The vegetation is impenetrable and contains a dense monoculture of *B. novae-zelandiae* roughly one and a half to two meters tall. The roost site adjoins an infrequently-travelled walking trail, along which *C. geminata* becomes common. Also within the roost site and outside the patch of blechnum fern, other plants present in the understory include *M. pustulatum*, *G. rupestre*, crown fern (*Blechnum discolor*), *U. europaeus* and *B. repanda*. There is a gap in the canopy above the standing water and above the blechnum fern patch. Outside of this, trees within the roost site include mostly *P. arboreus* as well as *C. grandifolia*, *C. robusta* and *C. serratus*.

SITE 12

This roost site is situated along the crest of a moderately steep ridge with an average slope of approximately 45 degrees. The site is located roughly 33 meters from the nearest stream and 850 meters from the nearest lake. The ground is covered with a thick layer of leaf litter and *M. pustulatum*. The forest in this general area has a fairly open understory, apart from the location of the roost site. At the roost site, numerous winding vines, trees and downed branches make passage impossible. This combined with a thick blanket of M. *pustulatum* provide ideal hiding space for the pāteke. Plants within the understory include *G. rupestre*, *U. europaeus*, *B. repanda*, *M. excelsum*, *M. australis*, *A. oblongifolium*, several mature *B. darwinii* and bushlawyer (*Rubus cissoides*). The canopy in the area is four and a half to five meters tall and contains *P. arboreus*, *C. grandifolia* and *C. robusta*.

SITE 13

This roost site is situated adjacent a stream fork at the far south end of the wildlife sanctuary, approximately 1,810 meters south of the nearest lake. The roost site is characterized by a dense stand of *B. novae-zelandiae* mixed with a few *C. geminata*, which grows one and a half to two meters in height. The fern and grass patch is approximately 12 meters long by 12 meters wide. Beneath this, the ground is damp and uneven. This understory and surrounding areas within the roost site are impenetrable due to the dense vegetation as well as numerous downed branches. Canopy over the fern/grass stand is open, with the surrounding trees including *C. robusta*, *C. grandifolia*, *C. australis*, *P. arboreus*, *B. repanda* and *B. darwinii*. The surrounding canopy extends to a maximum height of seven meters.

SITE 14

This roost site is situated at the bottom of a hill, adjacent to an infrequently-travelled walking trail. The hill slope at the roost site is roughly 30 degrees. The site is approximately seven meters west of the faultline stream and approximately 970 meters southwest of the nearest lake. The roost site is characterized by a dense stand of *B. novae-zelandiae* that grows one and a half to two meters in height. The ground beneath the fern stand is uneven, damp and spongy and is covered with a thick layer of dead fern fronds and leaves. *G. rupestre* and *A. serrata* grow along the perimeter of the fern stand. The canopy over the fern stand is open. Nearby trees include *S. digitata*, *P. arboreus*, *K. excelsa* and *B. repanda*. The canopy height in the close vicinity is approximately 6 meters.

SITE 15

This roost site is situated on a hillside adjacent a stream, approximately 1,514 meters south of the upper lake. The hillside has a slope of approximately 30 degrees. The roost site is characterized by a dense, nearly impenetrable stand of *B. novae-zelandiae* that grows one and a half to two meters in height. *B. discolor* and gully fern (*Pneumatopteris pennigera*) are also found within the fern stand. The ground beneath the fern stand is damp and muddy and is covered with leaf litter and dead ferns. The understory within the roost site also contains *G. rupestre*, *A. bulbiferum*, *U. uncinata*, *M. excelsum* and *B. repanda*. Canopy trees within the roost site are primarily *C. grandifolia* and *S. digitata*. The maximum canopy height within the roost site is four to five meters. However, the canopy grows much taller in surrounding areas and on the opposite side of the stream.

SITE 16

This roost site is situated along either side of a section of stream, approximately 370 meters upstream of the upper lake. The immediate area is flat and wide with a heavily saturated ground. The ground is covered in places by a thick matt of dead grasses. The understory is nearly impenetrable and grows one and a half to two meters tall. Approximately 80-90 percent of the understory consists of *C. geminata* and is scattered with *B. novae-zelandiae*. Other plants found within the understory include kawakawa *M. excelsum*, *M. australis*, *S. sylvatica*, *B. darwinii*, *B. repanda*, *A. bulbiferum* and *G. rupestre*. *R. cissoides* and *M. pustulatum* vines grow throughout the understory and up tree trunks into the canopy. There is a gap in the canopy just above the roost site. Saplings within the site, as well as mature nearby trees include *C. grandifolia*, *C. robusta*, *P. arboreus*, *S. digitata* and *C. medullaris*.

3.4.4 Roost Proximity to Lakes

After data were adjusted to account for survey bias, mean roost distance to the nearest lake was calculated for each transmittered bird as well as the mean error for the accuracy of each daytime telemetry fix (Table 3-4 and Figure 3-9).

Table 3-4. Mean roost distance to nearest lake and mean error of accuracy for each daytime telemetry fix for lake pāteke (1-3) and bush pāteke (4-10) in meters.

Bird ID	Nearest Roost	Furthest Roost	Mean Distance	Mean Error	No. Observations
1	0	167	4.14	12.7	141
2	0	3	1.00	10.9	29
3	0	89	4.00	16.7	196
Mean	0	86.33	3.00	13.4	122
SD	0	82.03	1.73	3.0	85.11
4	0	429	48.00	24.9	117
5	0	1047	165.00	21.6	75
6	0	1862	608.00	25.3	69
7	0	1253	1161.00	22.1	83
8	0	983	602.00	25.8	41
9	418	674	483.00	19.4	33
10	0	1877	1433.00	23.3	53
Mean	59.71	1160.714	642.86	23.2	67.29
SD	157.99	552.3	500.57	2.3	28.44
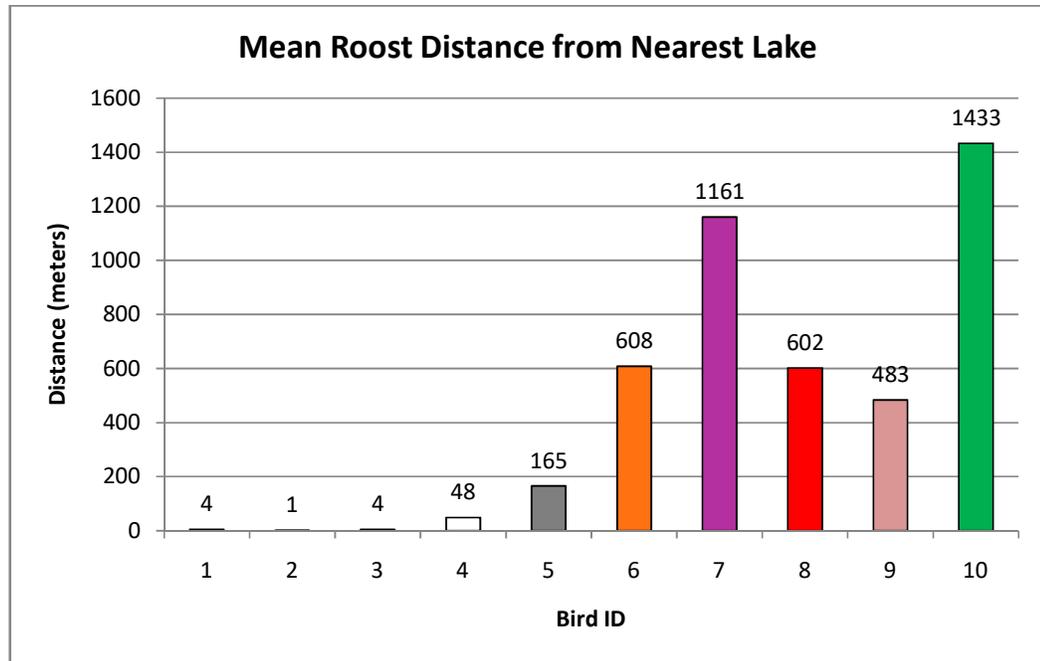
Figure 3-9. Mean roost distance to nearest lake for lake pāteke (1-3) and bush pāteke (4-10) in meters.

Lake pāteke had a mean roost distance to the nearest lake of 3 meters (SD = 2) and bush pāteke had a mean roost distance to the nearest lake of 643 meters (SD = 501). The mean error in accuracy of daytime telemetry fixes for lake pāteke was 13.4 meters (SD = 3.0) while the mean error in accuracy of daytime telemetry fixes for bush pāteke was 23.2 meters (SD = 2.3).

The mean roost distances to the nearest lake for lake pāteke were significantly shorter than that of bush pāteke (P = 0.017).

3.4.5 Temporal Roost Patterns

All seven bush pāteke roosted either within the flock site, within the bush, or a combination thereof. The proportion of daytime flock site telemetry fixes to overall daytime telemetry fixes was calculated for each bush pāteke for every month that they

carried a transmitter (Figure 3-10 through Figure 3-16). The cumulative proportion of daytime flock site telemetry fixes to overall daytime telemetry fixes was also calculated for all bush pāteke combined for every month that they carried a transmitter (Figure 3-17). Since the timeline in which transmitters were fitted to and removed from pāteke was staggered, the cumulative timeline only shows the period in which a majority of transmittered birds overlapped. The shaded blue areas represent the pāteke flocking season (i.e., the months in which the proportion of flock site fixes would presumably be the highest).

Figure 3-10. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 4.
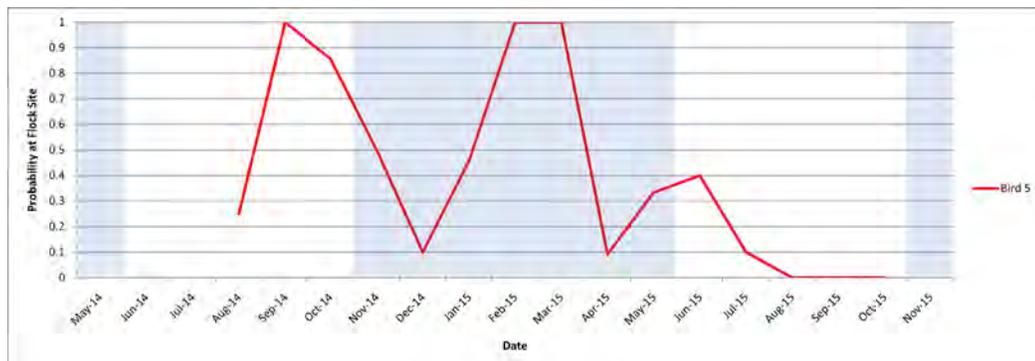
Figure 3-11. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 5.
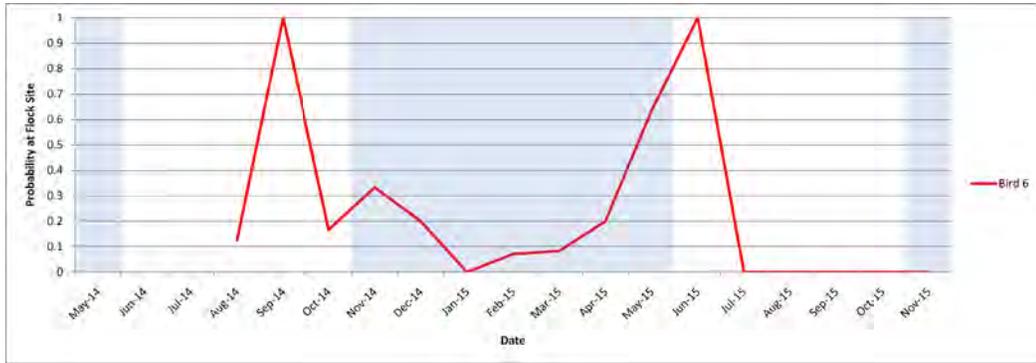
Figure 3-12. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 6.
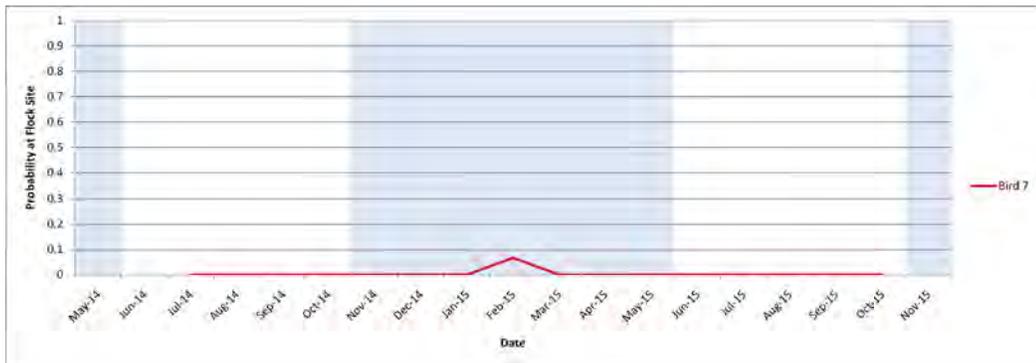
Figure 3-13. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 7.

Figure 3-14. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 8.

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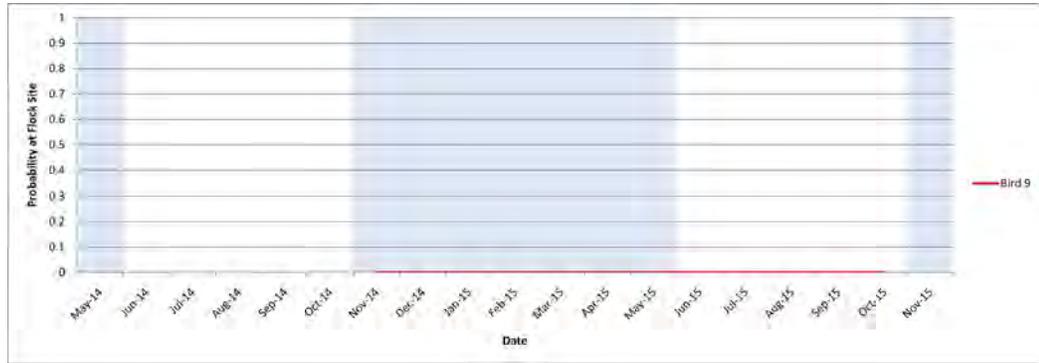
Figure 3-15. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 9.
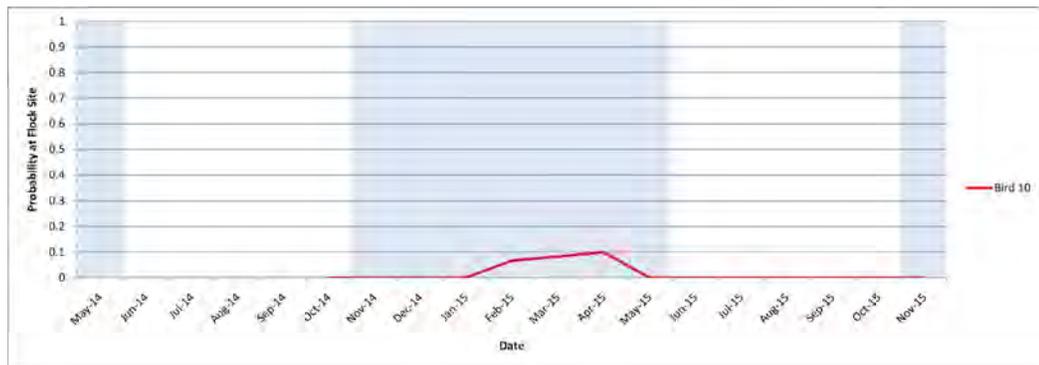
Figure 3-16. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for bird 10.
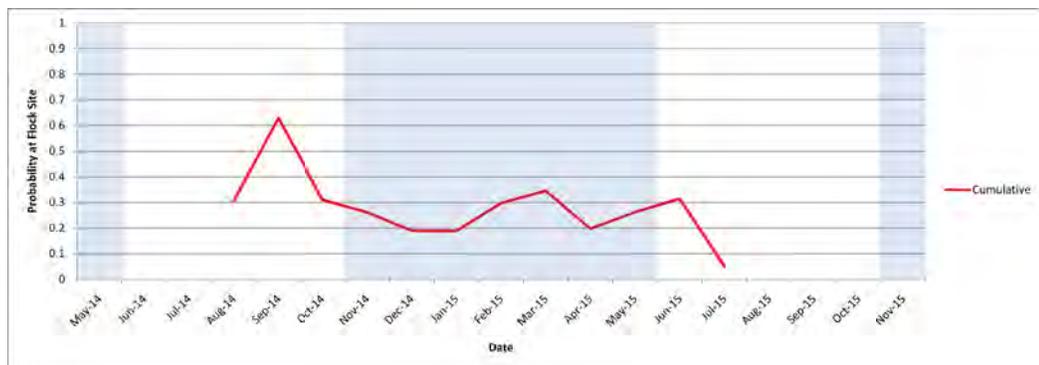
Figure 3-17. Breakdown by month of proportion of flock site telemetry fixes to all daytime telemetry fixes for all bush pāteke combined.

After data were adjusted to account for survey bias, distance from the nearest lake was plotted for every daytime telemetry fix chronologically for each of the 10 transmittered birds to display individual roost movements over time in relation to lake proximity.
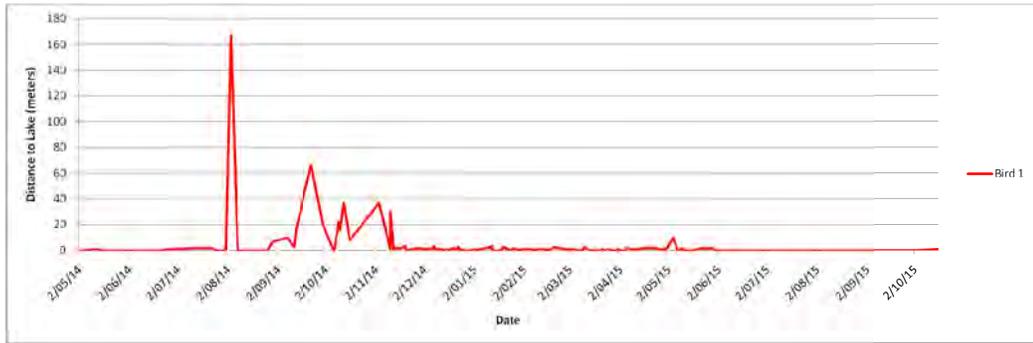
Figure 3-18. Daytime telemetry fix distances from nearest lake for bird 1.

Figure 3-19. Daytime telemetry fix distances from nearest lake for bird 2.
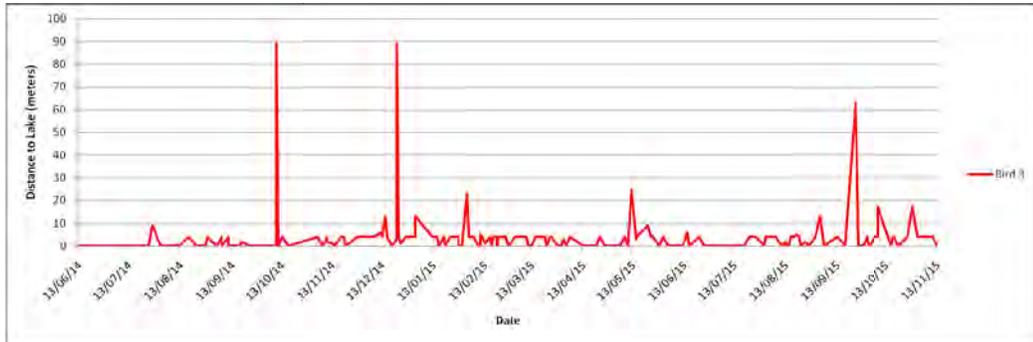
Figure 3-20. Daytime telemetry fix distances from nearest lake for bird 3.
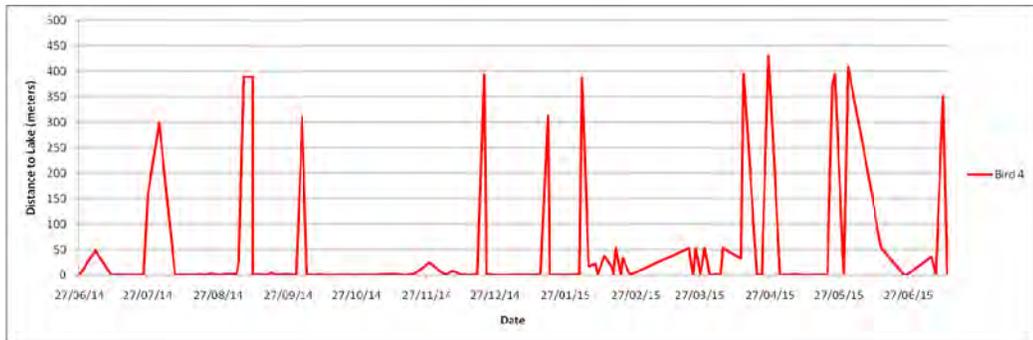
Figure 3-21. Daytime telemetry fix distances from nearest lake for bird 4.
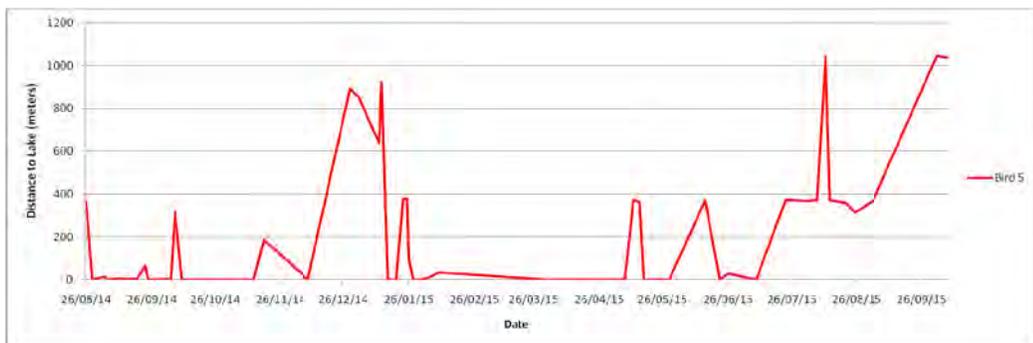
Figure 3-22. Daytime telemetry fix distances from nearest lake for bird 5.
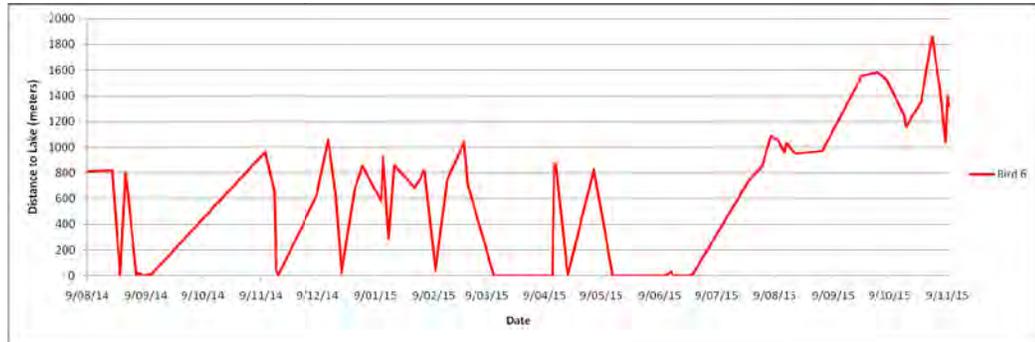
Figure 3-23. Daytime telemetry fix distances from nearest lake for bird 6.

Figure 3-24. Daytime telemetry fix distances from nearest lake for bird 7.

Figure 3-25. Daytime telemetry fix distances from nearest lake for bird 8.
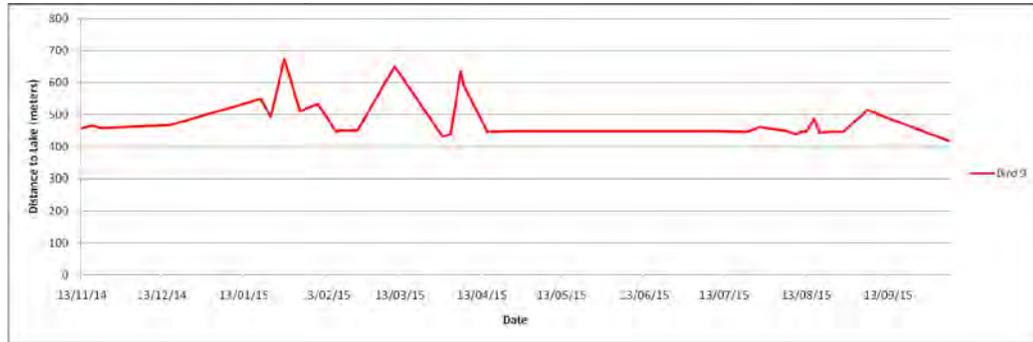
Figure 3-26. Daytime telemetry fix distances from nearest lake for bird 9.
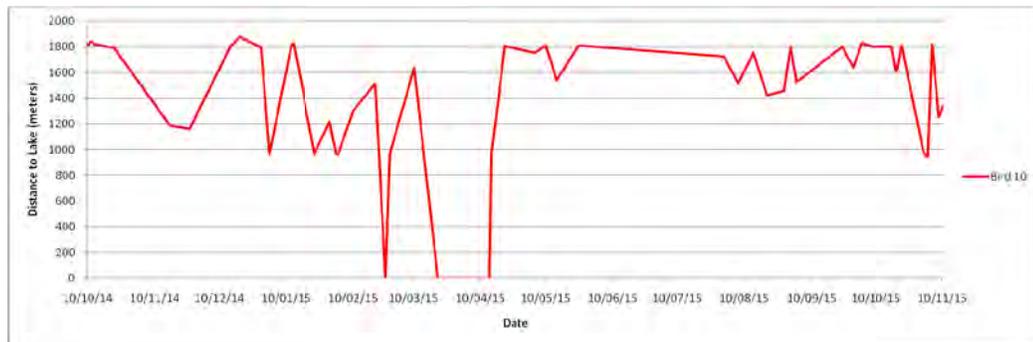
Figure 3-27. Daytime telemetry fix distances from nearest lake for bird 10.

3.5   Discussion

3.5.1   Core Roost Area Size

The difference in core roost area sizes of lake pāteke versus bush pāteke was not statistically significant. However, the range in sizes of core roost areas amongst bush pāteke (Range = 5.806) was much larger than that of lake pāteke (Range = 1.177), with three of the seven bush pāteke having core roost areas greater than five hectares, while three others had core roost areas under one hectare. Individual circumstances were likely to have played an important role in the outcome of each bird's core roost area size. The history of bird 8 prior to his brief stay at the Wellington Bird

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Rehabilitation Centre is unknown. Thus, upon his release along a forested stream at Zealandia, his initial movements were likely more a reflection of his explorations in deciding upon suitable locations in which to roost and forage. This most certainly contributed to his having four separate core roost polygons, the most of any study bird. This exploration and familiarization with his new environment likely also contributed to his having the second largest overall core roost area.

Three bush pāteke (birds 4, 7 and 9) maintained only single-polygon core roost areas under one hectare, whose sizes were more analogous with that of lake pāteke. At 0.836 hectares, bird 4 had the smallest core roost area of the bush pāteke. On numerous occasions he revisited and roosted along the same short stretch of stream (preferred roost site 16), roughly 370 meters south of the flock site. However, this was not frequent enough to be considered a core roost area by the 50% KUD analysis. Therefore, his only core roost area consisted of a single polygon on the upper lake, within the flock site.

Bird 7 maintained a 0.883-hectare core roost area which was in the bush, far-removed from any lake. As is discussed in Section 3.4.3, this is the only core roost area (preferred roost site) away from the lakes that contains standing water. Although the standing water feature is small (20m × 10m × <1m deep), it likely offers a more substantial source of aquatic invertebrate food than the fast flowing and minimally-vegetated streams, and could have acted as an anchor to the immediate area, even for the purposes of daytime roosting.

Bird 9 was the only female pāteke to receive a transmitter as part of the study and she maintained a single-polygon core roost area of 0.853 hectares. Little is known of differences in roosting behavior of male versus female pāteke. However, females of

many *Anas* species are known to maintain smaller home ranges (and likely smaller core areas), than their male counterparts (Derrickson, 1978; Ringelman, Longcore & Owen, 1982). It is possible that bird 9 may have been on a nest for part of the time she was being monitored, which would have caused her to be tracked to the same daytime location for at least one month.

Although no statistically significant findings were made when comparing core roost area sizes between the predefined "bush pāteke" and "lake pāteke" groups, review did illuminate the finding that, with the exception of the female transmittered bird, small core roost areas do appear to be correlated with presence of standing water features. Indeed, when a Wilcoxon rank-sum test was performed on the data, segmenting the two groups based not on whether they were captured in the bush at night or near the lake in the daytime, but upon whether they maintained core roost areas exclusively adjacent standing water, birds with core roost areas exclusively adjacent standing water had significantly smaller core roost areas than birds with core roost areas in the bush (P = 0.032).

3.5.2   *Core Roost Area Overlap*

With the exception of the flock site, core roost area overlap was virtually nonexistent. Five instances of minimal overlap occurred, where less than 10% of core roost area between two birds overlapped. Two of these overlaps are attributed to oversmoothing by the KUD analysis of core roost areas of bird 5 and bird 6, which inaccurately depict their flock site core polygons as extending west across the small peninsula to overlap with the core roost area of lake bird 3. A third instance of minimal overlap occurred between bird 8 and bird 9, where 0.60% of their core roost area overlapped. This can also be attributed to oversmoothing. The two remaining instances of minimal

core roost area overlap occurred where the flock site core polygon of bird 8 overlapped with the flock site core polygons of bird 5 and bird 6. This outcome reflects a true overlap of core areas. However, the overlap is represented as being minimal because bird 8 maintained three other substantially-sized core roost areas in the bush.

While there were no instances of core roost area overlap in the bush, there were several occasions where bush pāteke roosted in the same location. On a few occasions, they roosted in the same bush location at the same time. Due to the incredibly dense understory that was present at nearly all of these roost locations, it is unknown whether either bird was aware of the other's presence. The simultaneous use of these roost locations could have been a coincidence, and could indicate that these locations contain optimal roost site conditions, and/or that they are located close to an ideal foraging corridor. This explanation would seem to fit with the overlap occurring at preferred roost site 14 (Figure 3-8) since the site is adjacent the main stream that leads from the south end of the valley up to the flock site. Moreover, the two birds that roosted here (bird 7 and bird 10) were primarily forest birds that were found roosting at this intermediate location shortly before and/or after roosting briefly at the flock site.

One other explanation of this overlap could be that these roost locations were once the site of a nest, and that these birds were revisiting their natal territory. In a different natal territory within Zealandia that was highly visible and accessible, pāteke juveniles were observed to return periodically, even well after their fledging age and into their second year. This scenario would seem fitting in the case of overlap at preferred roost site 9 (Figure 3-8) since the site was located near a hilltop and was far-

removed from any major foraging or travel corridor and as juveniles had been seen on camera in this location previously.

It is important to note that these occasions of overlap in bush site roosting are, by far, the exception and that no overlap occurred in core roost areas within the bush. Likewise, there was no overlap in core roost areas of the three lake pāteke, although occasional instances of pāteke roosting in the same location did occur. Because lake roosts were less obscured than bush roosts, pāteke were able to observe one another more readily. In occasions where a roost site was desired by more than one bird (or more than one pair), one would typically chase the other away rather than roost close together.

As expected, the highest occurrence of overlap by far occurred within the flock site, with four study birds sharing core roost areas. Moreover, several other non-transmittered birds were regularly observed to roost within the flock site. This demonstrates the essential nature of a suitable flock site to any sustainable pāteke population. However, the importance of suitable bush roost sites within relatively close proximity to the flock site should not be overlooked. The breeding portion of the population relies on more discrete locations removed from the communal flock site, and often from the open water, in order to breed and rear their young. Pāteke within Zealandia have shown that locations in which they prefer to roost are widely varied. Thus, it is important that this variety of habitats remain available to them in order to maintain pātekes' unique behavioral characteristics.

3.5.3 Preferred Roost Site Characteristics

Preferred roost site descriptions provide a synopsis of the characteristics of roost locations that pāteke gravitated towards. Preferred roost sites along the lake edges

were somewhat similar to those roost sites inhabited by pāteke within their stronghold populations up north, as described in literature (Dumbell, 1986; O'Connor et al., 2007; Weller, 1974). Zealandia's lakeside roosts, including the flock site, consist of flat banks lining lake edges, stream inlets, an abundance of tall sedges and rushes, and overhanging vegetation. Preferred lakeside roosts tended to offer greater plant species richness than preferred bush roost sites.

Preferred roost site descriptions are of particular importance for sites located in the bush, since very little is known of the bush roosts utilized by present day pāteke. All preferred bush roosts shared a common theme – incredibly dense and often impenetrable understory. All bush sites were also relatively close to streams, along which pāteke were seen foraging at night. Various species of fern were a common theme amongst all bush roost sites.

The most prominent feature found at six of the nine preferred bush roosts consisted of an incredibly dense monoculture understory of *B. novae-zelandiae*, under which lay watery mud. While an open to semi-open patch typically existed in the canopy above these dense fern patches, the ferns themselves provided ideal dark concealment in which pāteke could roost for the day. The three remaining preferred bush roosts also had a densely-vegetated understory, although the plant composition was more diverse and the canopy gap was less prominent. Two of the three sites did have *B. novae-zelandiae*, although in less abundance than at other sites.

Topography of each of the sites was variable, even within the individual sites themselves. Several of the bush roosts dominated by *B. novae-zelandiae* were nearly flat, but positioned at the bottom of very steep hills. The three preferred bush roosts with more mixed understory (and less ideal cover) were positioned at the tops of the

steep hills. In each case, pāteke were well adept at traversing the steep and overgrown terrain. In some cases, the steep downward gradient may provide an advantage for escape from predators, particularly where camouflage provided by dense understory cover is insufficient.

The variety amongst preferred roost sites at Zealandia reaffirms this unique bird's ability to survive in diverse conditions. Given that several of these birds have inhabited the forests of Zealandia for 10 or more years, individuals appear to have retained the behavioral plasticity to roost in diverse habitats successfully.

3.5.4 Roost Proximity to Lakes

Mean roost distance to the nearest lake was found to be significantly shorter for lake pāteke than for bush pāteke. The three transmittered lake pāteke had mean roost distances between 1 and 4 meters to the nearest lake edge. While two of the lake pāteke did roost further from the lake edge on very rare occasion, the occurrences were so few and the roost sites still relatively close by that they did not have a significant bearing on the birds' mean roost distances. This consistency in roosting nearly adjacent the lake edge would suggest that the lake is an essential component of a suitable roost site for these individuals.

Mean roost distance to the nearest lake was highly varied for bush pāteke , with bird 4 having the shortest mean roost distance (48 meters) and bird 10 having the longest mean roost distance (1,433 meters). Several bush pāteke split their roost time between the lake and the bush, which was reflected in their having mean roost distances that fell roughly midway between the distance of their flock site and bush roost distances. For three bush pāteke, nearly all of their observed roost locations were within the bush, suggesting that lakeside roost habitat is not an essential home range component

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for all pāteke. Moreover, bush pāteke who travelled between the flock site and their respective bush roosts (all except for bird 9) displayed that they are capable of recalling the location of the flock site as well as their bush roosts and that they are capable of walking distances of nearly one kilometer in some cases, between the two locations, on a regular basis.

3.5.5   *Temporal Roost Patterns*

An evaluation of the proportion of observed flock site roosts to overall roosts by month for all bush pāteke combined did not indicate any preference among the group to roost at the flock site during flocking season. Likewise, none of the bush pāteke individually displayed clear evidence of a preference for roosting at the flock site during flocking season, with the possible exception of bird 8. The majority of the time that bird 8 spent within the flock site was during flocking season. However, he spent relatively little time at the flock site even then, with his highest proportion of flock site fixes for any given month during the flocking season being 30%.

Interestingly, the single flock site roost fix obtained for bird 7 was in February, during the height of the flocking season. The same held true for the only three flock site fixes obtained for bird 10, which were obtained in February, March and April. Bird 6 actually appeared to display the opposite of what would have been expected. For the months of September 2014 and July 2015, 100% of this bird's daytime roost fixes were within the flock site. For every month of the 2014/2015 flocking season, however, the majority of his daytime observations were within the bush.

Although several bush pāteke carried their transmitters well into October and November 2015, no bush pāteke were observed within the flock site after July 2015.

These observations are consistent with the expectation that pāteke would avoid the flock site and instead roost in the bush outside of the flocking season.

The month-by-month breakdown of the proportion of time under observation that each bush pāteke spent within the flock site indicated that flocking season for Zealandia's pāteke population is not so clearly defined or adhered to. It also provided a more detailed representation of the variation in amount of time spent flocking between individual birds. This analysis, however, did not offer a more intricate breakdown of the frequency or extent to which individuals relocate their roost locations.

Figure 3-18 through Figure 3-27 provide a more thorough representation of the frequency and extent to which individuals moved between their roost sites. Although these line graphs represent only the distances of a given roost fix to the nearest lake, repetition of peaks and valleys of the same height (distance) in a given line graph are generally indicative of the individual moving repetitively between the same two or three roost sites. This pattern is perhaps most evident for bird 7, who frequently moved between preferred roost sites 11 (±1,200 meters) and 9 (±1,000 meters) (Figure 3-24).

The line graphs depicting individual movements between roost sites as they relate to lake proximity are not an entirely accurate method of representing actual distance travelled between roost sites since they do not accurately account for distances between consecutive roost sites. However, given the narrow and elongated layout of the valley and the position of the flock site to the north of nearly all preferred bush roosts, the line graph method paints a fairly clear picture of the general trends observed. This depiction also allows the viewer to generally deduce when the same

roost is being used repeatedly, even when the site is being accessed from roosts at varying distances.

This method of representing frequency and extent of individual movements between core roost areas underestimated the movements of lake pāteke, who frequently moved between two different roost sites which were both situated adjacent to the water's edge. That being said, even the greatest distance between two core roost areas of a single lake pāteke was minimal compared to the distances between roosts of the bush pāteke. It is evident that bush pāteke travel much further than lake pāteke between their roost sites and that they do so on a fairly regular basis.

Line graphs depicting actual distances between relocations would not have allowed differentiation between preferred roost sites and would not have been entirely accurate themselves, since intermediate daytime roost observations were inherently missed. It should be noted here that these line graphs are based on telemetry fixes which captured only a fraction of the bird's actual daily roost movements and so represent the minimal amount of movement between roosts. In reality, the amount of peaks and valleys of each line graph (movement between distant roost sites) was likely greater.

3.5.6   *Conclusions and Management Implications*

While the classification of individual birds into "bush pāteke" or "lake pāteke" was a useful tool for the purposes of project design and data analysis, results suggest behaviors may not be so clearly defined. Various results for the study birds tended not to be bimodal in their distribution, but lay somewhere within a broad spectrum. While the three lake pāteke tended to be very similar in their habits, the pre-ascribed "bush pāteke" (so ascribed because they were captured in the bush) displayed great variation

across nearly all facets of analysis. This phenomenon highlights the diversity of pāteke behavior and the extensive range of habitats that they are capable of occupying.

In general, lake pāteke tended to exhibit very similar roost behaviors to one another, nearly always sticking close to shore and maintaining core roosts which were close to one another and that did not overlap with other teal. Lake pāteke also occupied roost sites which were of strikingly similar composition. As will be discussed in Chapter 4, lake pāteke travelled comparatively short distances from their roosts to forage at night, which may be a result of their continued access to ample food at their lakeside roosts during the daytime. The tendency for all of their movements to occur within a much smaller footprint and close to open water would appear to be in keeping with the accounts of pāteke in the northern North Island populations, who are described as staying close to the water's edge and travel only short distances into pastures, tidal pools, etc. at night to forage.

It is not clearly understood whether this lake-centric life is the ideal for all pāteke at Zealandia, meaning that the bush pāteke have been pushed into marginal habitat. The reality that observations for several bush pāteke were almost exclusively within the forest would suggest, however, that forest habitat is sufficient. Likewise, the observation of other bush pāteke splitting their time between the flock site and distant bush roosts, as well as evidence that they repeatedly returned to these bush roosts, would suggest that the bush is a suitable environment for them.

One of the most striking differences between lake roosts and bush roosts when considering their functionality is that lakeside roosts offer a quick route of escape, wherein pāteke can take flight over water to evade predators. Bush roosts are far too

densely-vegetated to offer a flighted escape. This combined with the fact that pāteke are reluctant flyers and tend to freeze in the presence of predators would not bode well for bush pāteke who inhabit a predator-infested bush. When applying this logic to pāteke populations up north where bush and other surrounding land contain mammalian predators, it is easy to see how pāteke who select roosts near open water have a strong advantage over those who roost in the bush.

From this perspective it makes sense to focus conservation efforts in open coastal wetland habitats in the north. The plentiful waterfront real estate provides ample space in which pāteke can choose roosts which allow them to evade predators. Moreover, because pāteke who roost along the water's edge tend to hold much smaller roost areas (and home ranges), a smaller space would accommodate a larger number of birds. This becomes important when considering cost and effort associated with site maintenance, ongoing predator trapping and surveillance of the pāteke population.

Concentration of pāteke conservations efforts within coastal wetlands of the northern North Island over the past 15 years has saved the pāteke from the brink of extinction. With numbers continuing to trend upward and the fate of the species growing increasingly more secure, it may be time to consider addition of another facet to their conservation. More recently, this little-known bird has been gaining public attention. Its unique and quirky behavior and hallmark conservation success story have led to increased awareness and interest from the public. Early management efforts which were largely confined to coastal Northland, Great Barrier Island and Coromandel were undoubtedly essential to the species' preservation. However, if this continues to be the only primary means of preserving the species, circumstances will naturally

select for pāteke who roost along open water and the species as a whole will continue to lose the bush-dwelling trait that makes it so unique.

Ongoing mammalian predator control is an essential feature to a suitable pāteke environment, and so potential release sites are extremely limited. However, with persistent and increasing focus being placed on predator control throughout the country, not just for the protection of pāteke, but for the protection of many of New Zealand's vulnerable fauna, more and more suitable release sites are likely to become available. While wetlands features remain an essential feature of any suitable release site for the purposes of flocking, primarily forested sites should also be given ample consideration.

4   Spatial and Temporal Foraging Patterns

4.1   Introduction

Rowcliffe et al. (2014) assert that all animals must divide their time between activity and rest and that, while activity is far more energetically costly than rest, it is essential to life. The daily shift in pāteke behavior from roosting (rest) to foraging (activity) is accompanied by a significant increase in energy expenditure. While this increase in energy expenditure is necessary in order to obtain food, it is imperative that individuals find ways to optimize its benefits (e.g. amount of food consumed) while minimizing its costs (Downes, 2001). One means by which animals can optimize the benefits of energy expenditure is by foraging in locations in which food resources are concentrated, thereby reducing energy allotted towards procuring food. While staying close to concentrated food sources would seem the most efficient option in all cases, there may be benefits in avoiding these resource-abundant locales, such as avoiding conflict with other individuals seeking the same resources.

Similar to our incomplete understanding of pāteke roost behavior, our present understanding of pāteke foraging behavior is largely limited to what is known of the foraging habits of pāteke residing in the remnant northern populations. Over a seven-day observation period at Great Barrier Island, Weller (1974) reported that teal fed almost exclusively within tidal estuaries, and that feeding was cyclical and tide-dependant. Dumbell (1986) notes that brown teal roosts are characteristically located proximate to feeding areas and that teal are well-known for their nocturnal feeding habits. Numerous reports indicate that pāteke habitually feed within boggy pastures and amongst emergent stream vegetation (Dumbell, 1986). Pāteke are known to be opportunistic feeders, with a more recent study concluding that pāteke feed on 78

different taxa, including a combination of terrestrial and aquatic invertebrates and vegetation (Moore et al., 2006).

Chapter 2 and Chapter 3 of this thesis identified considerable differences in home range attributes and roosting patterns between lake pāteke and bush pāteke. This chapter will analyze several facets of pāteke foraging behavior. The comparative lengths of streams and/or lake edge along which pāteke foraged will be evaluated for all 10 transmittered birds. Extent of foraging overlap will be determined at every camera location where a camera was in operation for at least 500 hours. Foraging hotspots will be identified based upon the proportion of pāteke sightings collected at each of the 144 camera locations in relation to the overall time each camera was in operation. As the latter two analyses are based on camera footage, results are not limited to the 10 transmittered birds, but rather, will incorporate data for all birds that could be distinguished as a specific bird.

4.2   Objectives

This chapter aims to identify foraging patterns of pāteke at Zealandia through the use of telemetry and motion-sensing cameras. It is hypothesized that individuals or pairs will consistently forage along the same section(s) of stream and that linear foraging ranges of bush pāteke will be longer than those of lake pāteke. It is anticipated that a greater number of individuals will overlap at cameras proximate to the flock site and that locations proximate to the flock site will have a higher frequency of pāteke camera recordings.

4.3   Materials and methods

4.3.1   Banding and transmitter fitting

As discussed in Chapter 2, 10 pāteke were captured and fitted with color and metal identification bands as well as transmitters between November 2013 and October 2014. This study used Holohil RI-2B transmitters with a minimal 12-month battery life. Transmitters weighed 11 grams and were fitted to birds using a backpack harness mount with built-in linen weak-link thread, in accordance with the requirements and procedures set forth in the DOC SOP for attaching radio and data-storage tags to birds (DOC, 2011).

One of the 10 transmittered birds was hand-netted at WBRC and released along a forested stream within Zealandia. The remaining nine were captured at Zealandia. Seven transmitters were fitted to birds known to utilize forested habitat (this includes the one wild bird transferred from WBRC and released in forested habitat). The remaining three transmittered pāteke are individuals who, prior to transmitter fitting, were observed to remain in specific locations along the lake edges.

Birds at Zealandia were captured using one of two methods. One lake bird was hand-fed and then hand-netted. The remaining eight study birds were keyed in to stationary feeders containing maize grits, which were positioned inside 1-meter x 1-meter x 2-meter wire mesh cages. Cages with feeders were placed along streams within the forested portions of Zealandia at six different locations, to ensure that the birds captured and fitted with transmitters were birds known to occupy forested habitat. The remaining three locations in which birds were captured and fitted with transmitters were along the edges of the upper and lower lakes. Refer to Figure 2-1 in Chapter 2 for a map depicting the capture location of each of the transmittered birds.

4.3.2 Use of telemetry and motion-sensing cameras to identify spatial and temporal foraging patterns

All telemetry tracking was done by foot using a Telonics TR4 receiver and handheld portable Yagi aerial antenna. Bird location points were collected using the homing in method. Due to the elusive nature of pāteke and the type of terrain and vegetation in which they live, visuals were not obtained for most observations. Rather, the location and accuracy of each observation was estimated based on strength of signal as it related to antenna directionality, topography, vegetation density and age of transmitter.

Pāteke were tracked at night to identify locations in which they foraged. On average, night tracking was carried out once per month. Individuals who utilized more obscure locations and/or covered greater distances resulted in having fewer night telemetry fixes. As nightly telemetry tracking was impractical due to its labor-intensive nature, motion-sensing video cameras were used to collect the majority of information on night time foraging behavior of pāteke.

Bushnell 8mp Trophy Cam motion-sensing video cameras were used to collect information on foraging behavior of pāteke. Once foraging locations were identified through telemetry, five motion-sensing camera traps were placed in increments along streams where pāteke foraged to assess the extent and nature of stream utilization. An additional six cameras were made available and were deployed from May 30, 2015 to October 20, 2015. Cameras were active 24 hours per day and, once triggered, were set to record video for 10 or 15 seconds. Cameras were set to allow a 15 second delay after each recording. Camera footage was assessed on a weekly basis and cameras

were relocated to further stream points or across neighboring streams and tributaries based on observations from the footage.

Use of motion-sensing video cameras permitted collection of data for all pāteke who passed the camera and so, did not limit analysis to the 10 transmittered birds. This comprehensive nature of data collection provided the opportunity to explore attributes of foraging behavior at the population level, including the number of individual birds who travel through specific stream corridors and frequency in which given stream corridors were travelled by pāteke.

4.3.3 Statistical Methodology

All night telemetry suggested that pāteke foraged along or within a few meters of streams or lake edges. In order to increase the likelihood that cameras captured pāteke footage, cameras were only placed along stream corridors and lake edges. As such, overall foraging range can be determined by measuring the distance along streams that connect all night time telemetry and camera observations.

Due to the infrequency with which night telemetry was carried out, and as cameras were limited in number and required frequent rotation throughout the study site, numerous stream corridors used for foraging were likely missed. To a large extent, foraging corridors that weren't identified by camera data or night telemetry could be extrapolated based upon roosts identified through daytime telemetry. Where two or more daytime fixes were located within 100 meters of each other, but where no night time data were collected, it is assumed that the bird foraged along the stream to that location before climbing uphill to the roost site.

For three of the 10 transmittered birds (bird 1, 5 and 10), there was insufficient data to safely assume the birds always followed the streams to forage. Rather, in these three

cases it is possible that the birds took "shortcuts" up and over hills in order to access the neighboring stream corridor. In these three cases, second scenario measurements were made to determine the overall foraging range distances in the event the birds did not travel the entire distance upstream from the stream fork, but rather crossed over the ridge of the separating hill.

Mean and standard deviation of foraging range distances were calculated for both the "stream exclusive" scenario and the "hill shortcut" scenario for lake pāteke and bush pāteke. Wilcoxon rank-sum tests were conducted for both scenarios to determine whether a significant difference in total length of foraging range existed between the lake pāteke and the bush pāteke.

The proportion of foraging range occurring along a lake edge to overall foraging range was computed for each bird and mean and standard deviation were calculated for lake pāteke and bush pāteke ranges. Wilcoxon rank-sum tests were conducted to determine whether a significant difference in proportion of lake edge to overall foraging range existed between the lake pāteke and the bush pāteke for both the "stream exclusive" and "hill shortcut" scenarios.

Extent of foraging overlap ("foraging density") was measured using data exclusively from camera traps and so, was not limited to the 10 transmittered pāteke. Foraging density was determined by counting the number of individual pāteke who were recorded at a given camera location. In order to eliminate the instance of low observed density due to an insufficient duration of camera recording hours, foraging density was only measured at camera locations where a camera was in operation for a minimum of 500 hours.

The frequency in which pāteke traversed specific stream locations was measured using data collected exclusively by cameras. This analysis permitted inclusion of both transmittered and non-transmittered birds. Using a method suggested by Ridout & Linkie (2009), all pāteke video clips were grouped into their respective one-hour intervals at each camera location to determine the total number of hours which contained pāteke footage ("pāteke hours") at a given camera location. The proportion of "pāteke hours" to total hours a given camera was in operation at a site was calculated to determine pāteke frequency at each of the 144 camera locations.

4.4   Results

4.4.1   Linear foraging range

Linear foraging range distances were measured for 10 pāteke who had between 47 and 261 observations (via day and night telemetry and camera combined). Lake edge foraging distances and combined total foraging distances (lake edge + stream) were measured for each bird. For birds 1, 5 and 10, alternate foraging distances that accounted for potential use of "hill shortcuts" were also measured. Mean and standard deviation were calculated for lake pāteke and bush pāteke linear foraging range distances (Table 4-1).

The proportion of distance foraged along lake edge to overall distance foraged was calculated for all 10 transmittered birds for both "stream exclusive" and "hill shortcut" scenarios. Mean and standard deviation were calculated for proportion of foraging range occurring along a lake edge to overall foraging range for lake pāteke and bush pāteke for both "stream exclusive" and "hill shortcut" scenarios (Table 4-1).

Table 4-1. Foraging range distances for "stream exclusive" and "hill shortcut" scenarios and percent of distance foraged along lake edge to overall forage distance for all 10 transmittered birds.

Bird ID	Distance along lake edge (m)	Stream Exclusive		Hill Shortcut	
		Total distance (m)	% distance along lake edge	Total distance (m)	% distance along lake edge
1	978	1492	65.6%	1316	74.3%
2	334	436	76.6%	436	76.6%
3	236	905	26.1%	905	26.1%
Mean	**516**	**944**	**56.1%**	**886**	**59.0%**
SD	**403**	**529**	**26.6%**	**440**	**28.5%**
4	68	1214	5.6%	1214	5.6%
5	319	2934	10.9%	2445	13.1%
6	164	3899	4.2%	3899	4.2%
7	0	1273	0.0%	1273	0.0%
8	150	1179	12.7%	1179	12.7%
9	0	1230	0.0%	1230	0.0%
10	136	3797	3.6%	3331	4.1%
Mean	**120**	**2218**	**5.3%**	**2082**	**5.7%**
SD	**111**	**1277**	**4.9%**	**1151**	**5.4%**

Using the "stream exclusive" scenario, lake pāteke had a mean linear foraging range distance of 944 m (SD = 529) and bush pāteke had a mean linear foraging range distance of 2218 m (SD = 1277). Using the "hill shortcut" scenario, lake pāteke had a mean linear foraging range distance of 886 m (SD = 440) and bush pāteke had a mean linear foraging range distance of 2082 m (SD = 1151).

Using the "stream exclusive" scenario, lake pāteke had a mean lake edge foraging proportion of 56.1% (SD = 26.6%) and bush pāteke had a mean lake edge foraging proportion of 5.3% (SD = 4.9%). Using the "hill shortcut" scenario, lake pāteke had a mean lake edge foraging proportion of 59.0% (SD = 28.5%) and bush pāteke had a mean lake edge foraging proportion of 5.7% (SD = 5.4%).

Maps depicting linear foraging range distances as well as daytime and night time telemetry observations and camera trap observations for all 10 birds are included in the pages below (Figure 4-1 through Figure 4-10).
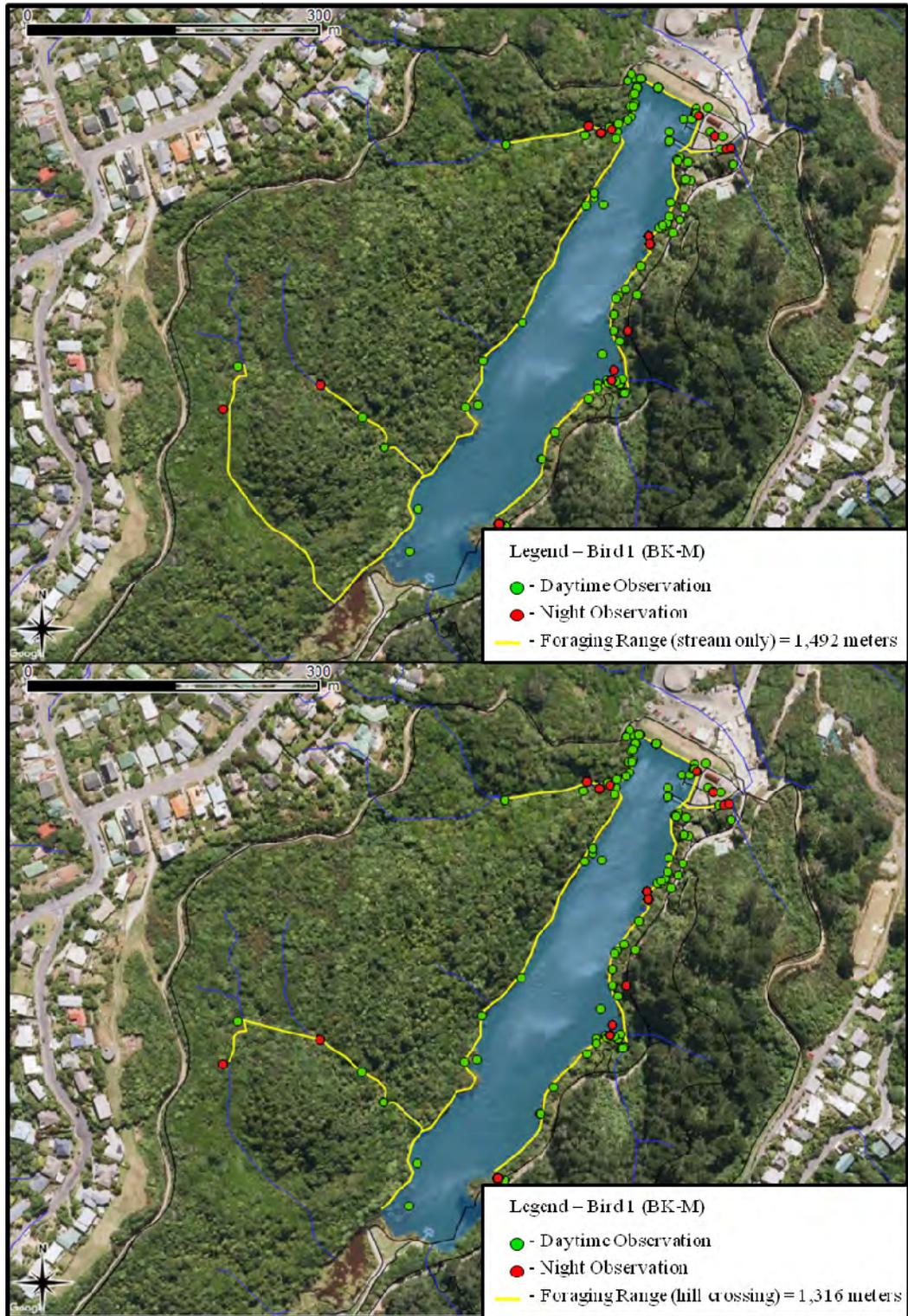
Figure 4-1. Linear foraging range for bird 1.

Figure 4-2. Linear foraging range for bird 2.
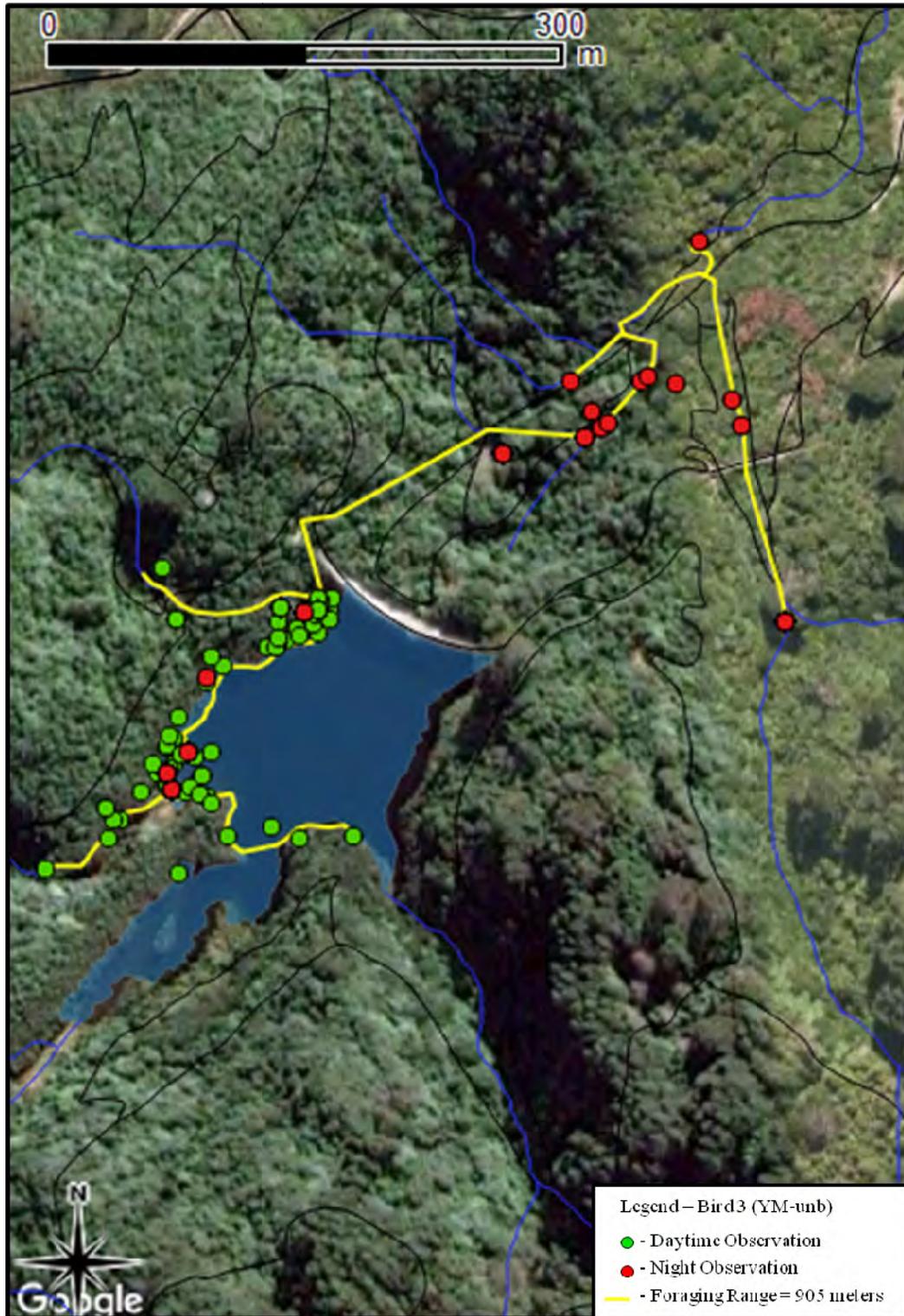
Figure 4-3. Linear foraging range for bird 3.
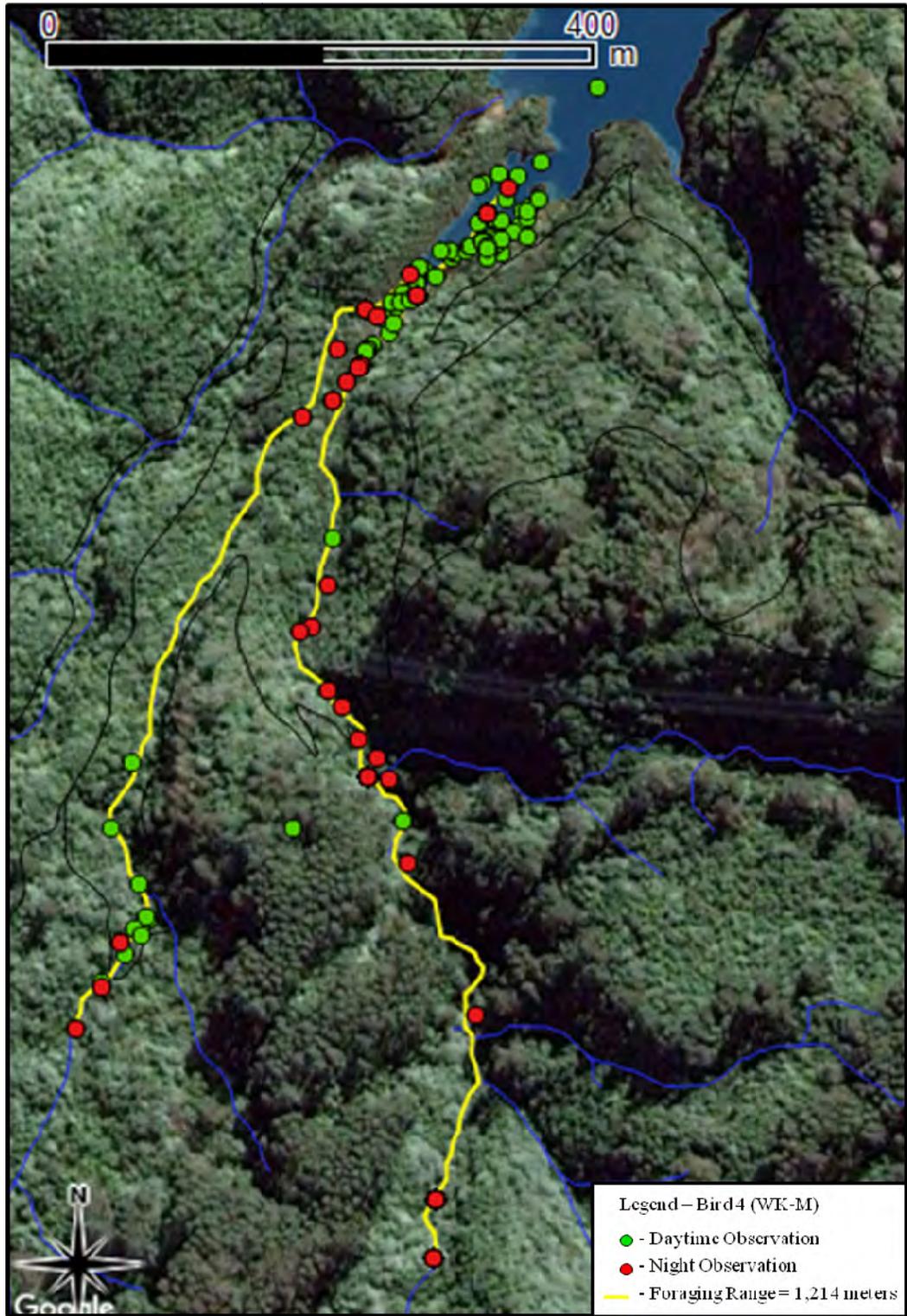
Figure 4-4. Linear foraging range for bird 4.
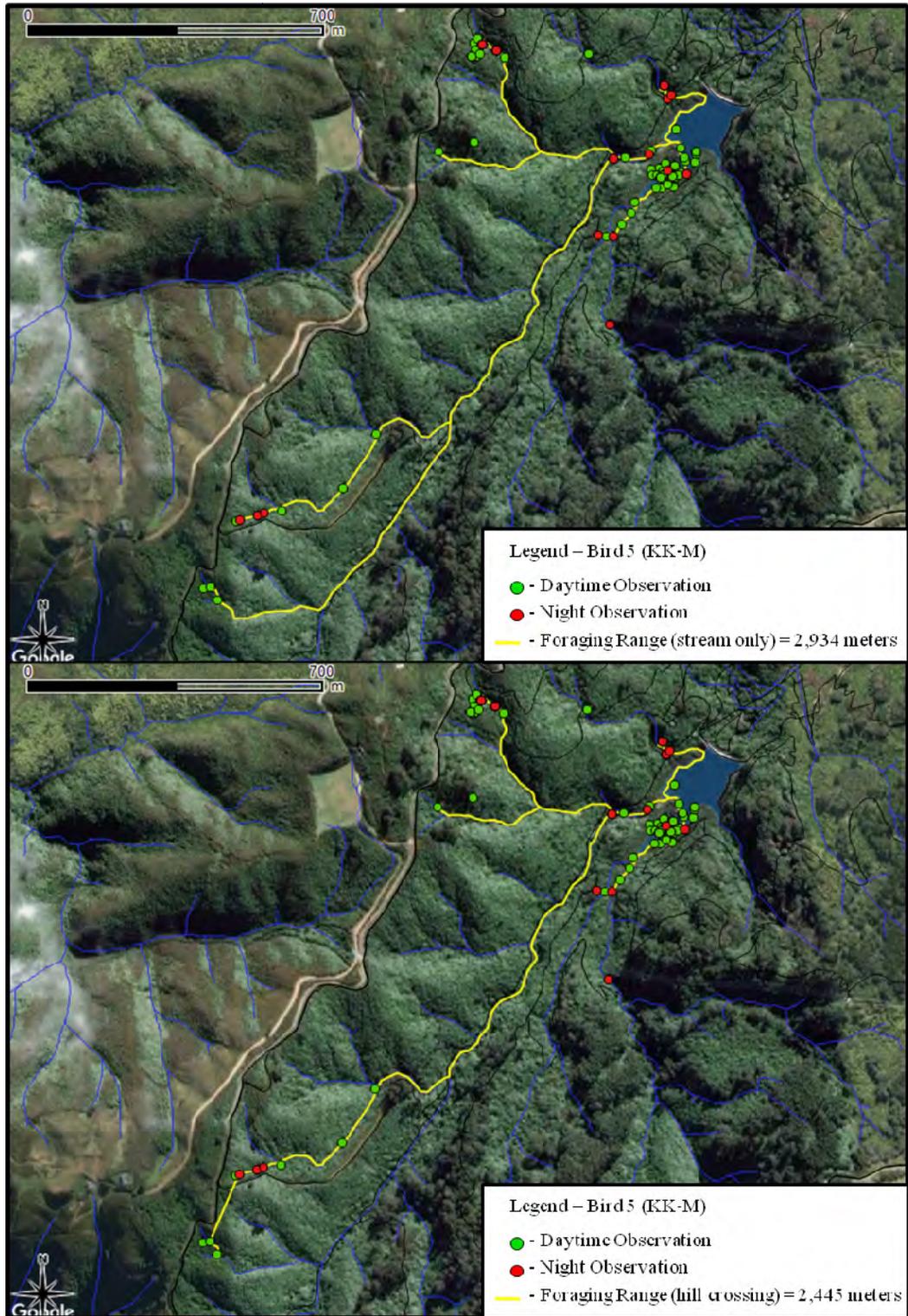
Figure 4-5. Linear foraging range for bird 5.
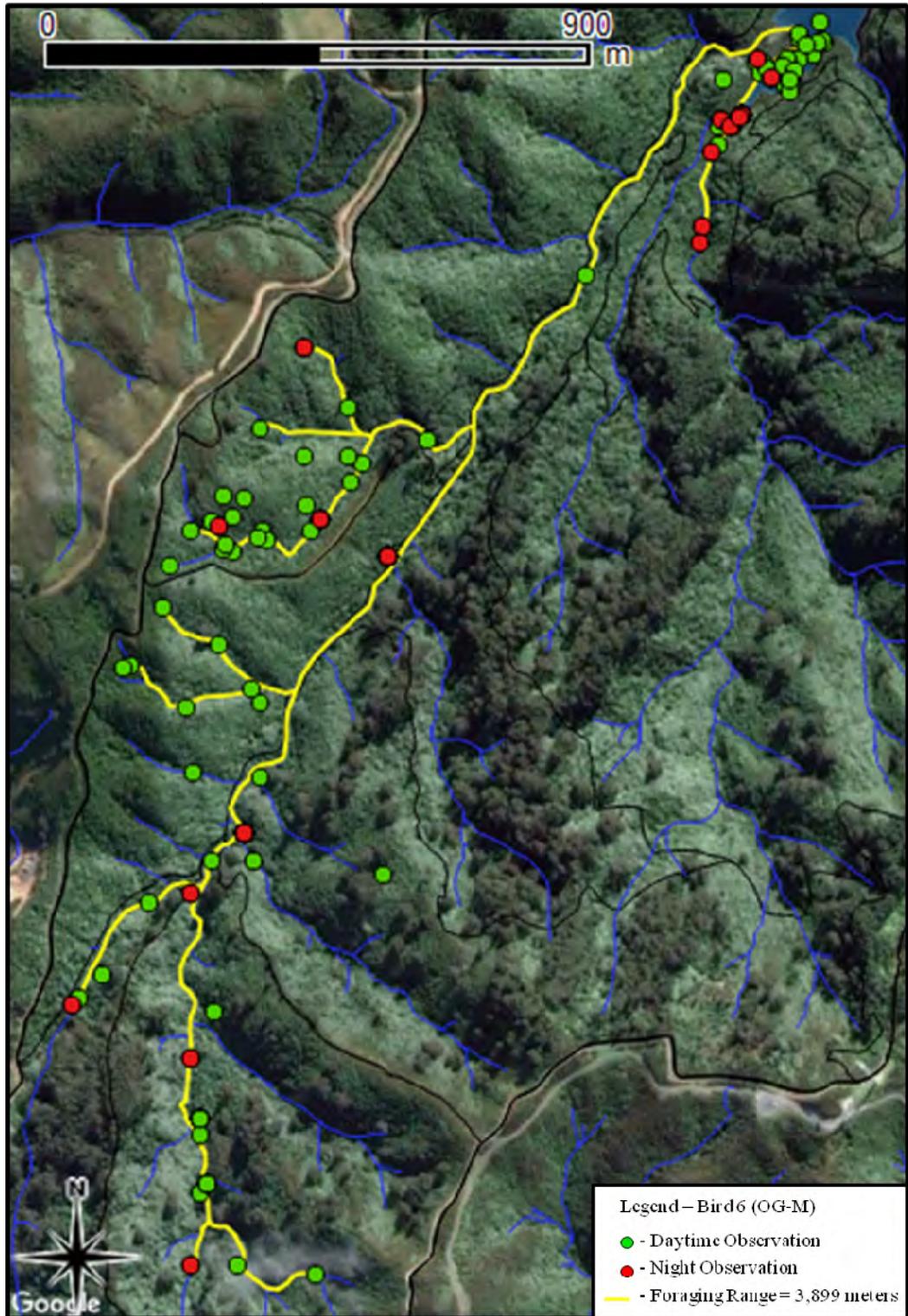
Figure 4-6. Linear foraging range for bird 6.
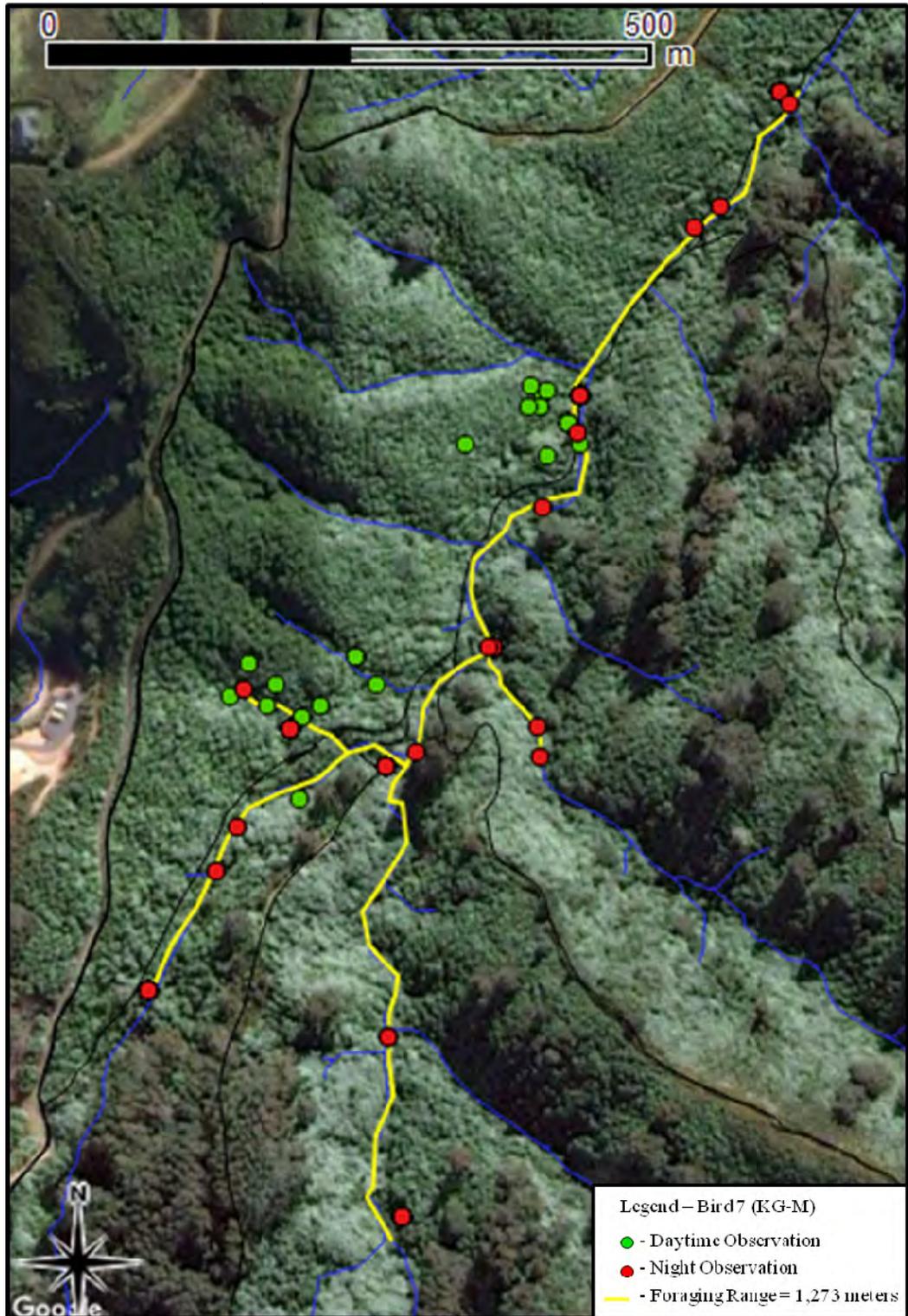
Figure 4-7. Linear foraging range for bird 7.
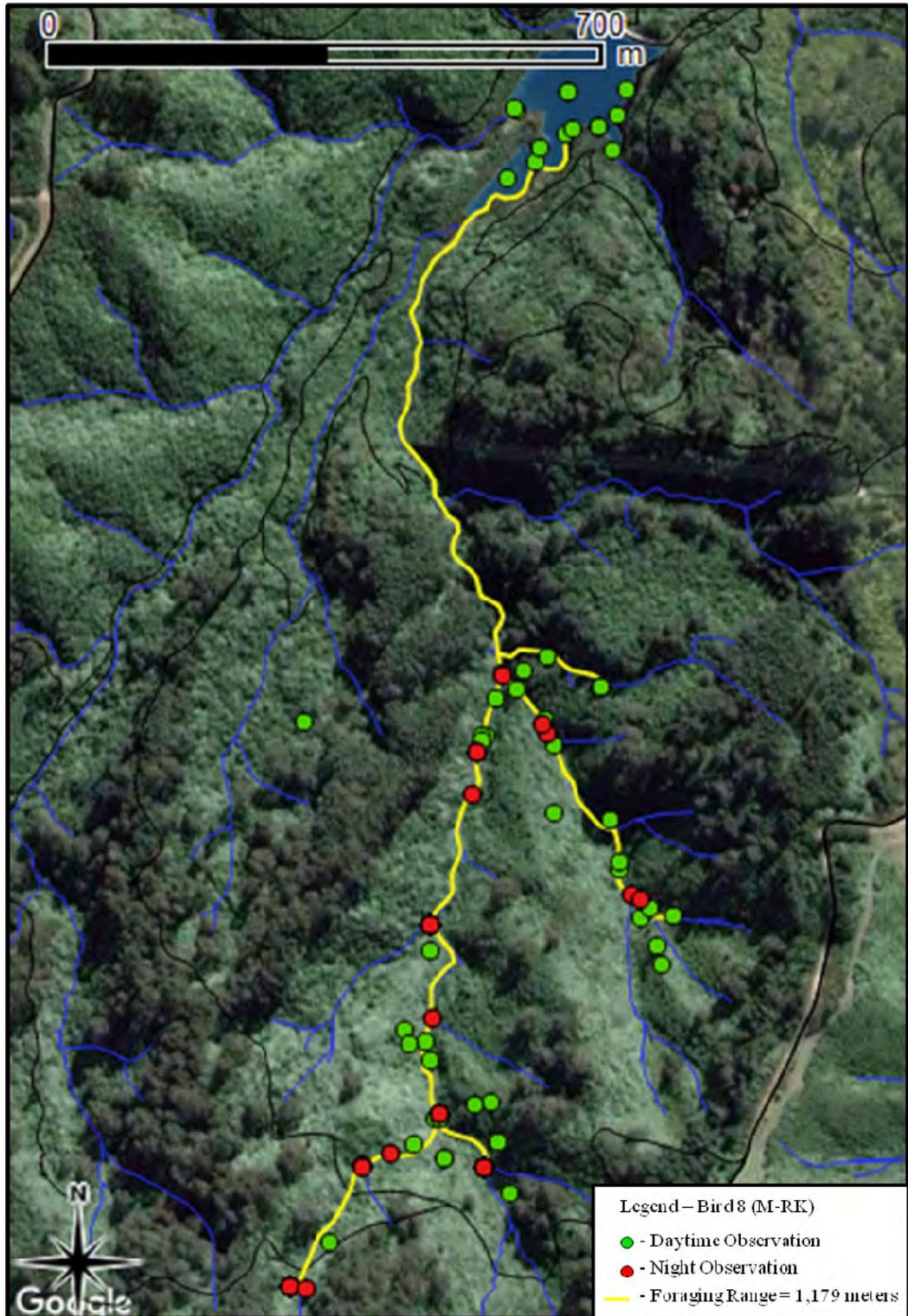
Figure 4-8. Linear foraging range for bird 8.
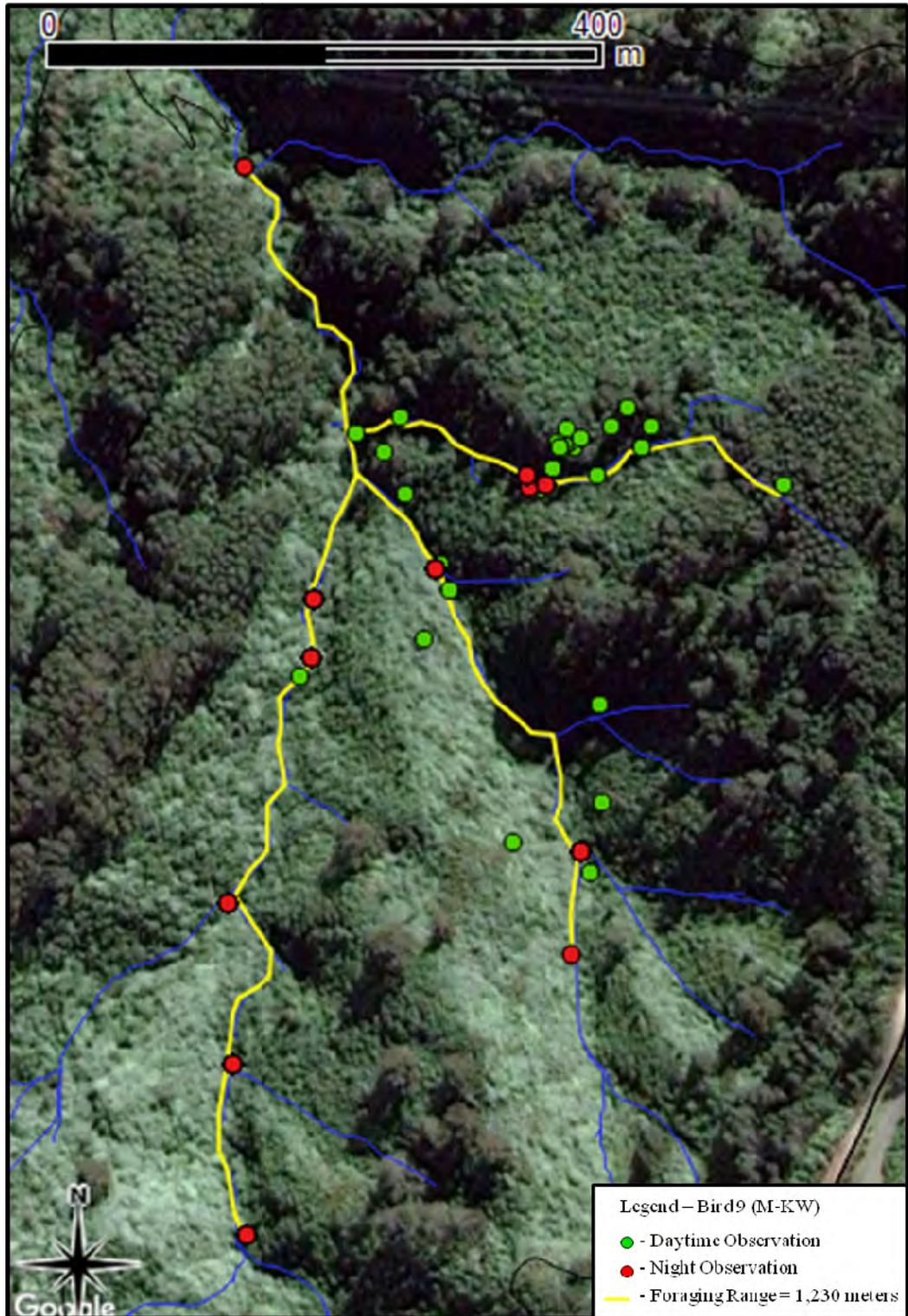
Figure 4-9. Linear foraging range for bird 9.
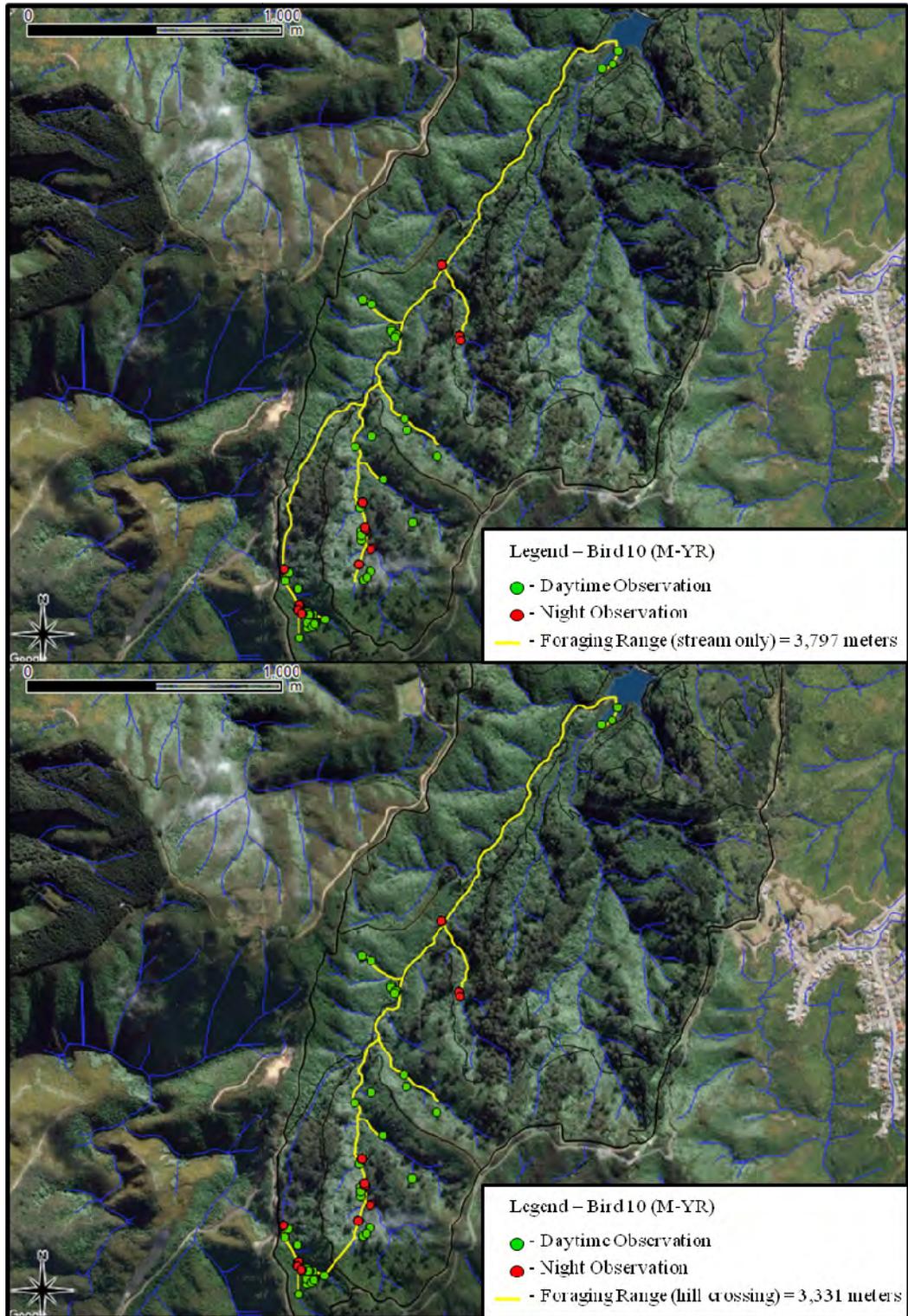
Figure 4-10. Linear foraging range for bird 10.

Using the "stream exclusive" scenario, the overall linear foraging range distances of lake pāteke were not significantly smaller than that of bush pāteke (P = 0.183). Likewise, using the "hill shortcut" scenario, the overall linear foraging range distances of lake pāteke were not significantly smaller than that of bush pāteke (P = 0.183).

Using the "stream exclusive" scenario, the proportions of lake edge foraging range to overall linear foraging range for lake pāteke were significantly greater than those of bush pāteke (P = 0.017). Likewise, using the "hill shortcut" scenario, the proportions of lake edge foraging range to overall linear foraging range for lake pāteke were significantly greater than those of bush pāteke (P = 0.017).

4.4.2   Foraging density

A total of 43 camera locations were determined to have a camera in operation for a minimum of 500 hours. Foraging density was determined for each of these 43 locations. These locations were found to show between zero and 10 pāteke traversing the same location. Foraging density was greatest at the camera location proximate to the mouth of the main stream leading directly into the flock site and at the camera location along the same stream approximately 260 meters upstream. Travelling 270 meters further upstream away from the flock site, the stream is still utilized by seven different pāteke. A large section of the faultline stream is also readily utilized by four different pāteke.

Foraging density at each of the 43 selected camera locations is shown on the map below, with circle size increasing relative to the number of pāteke observed at that location (Figure 4-11).
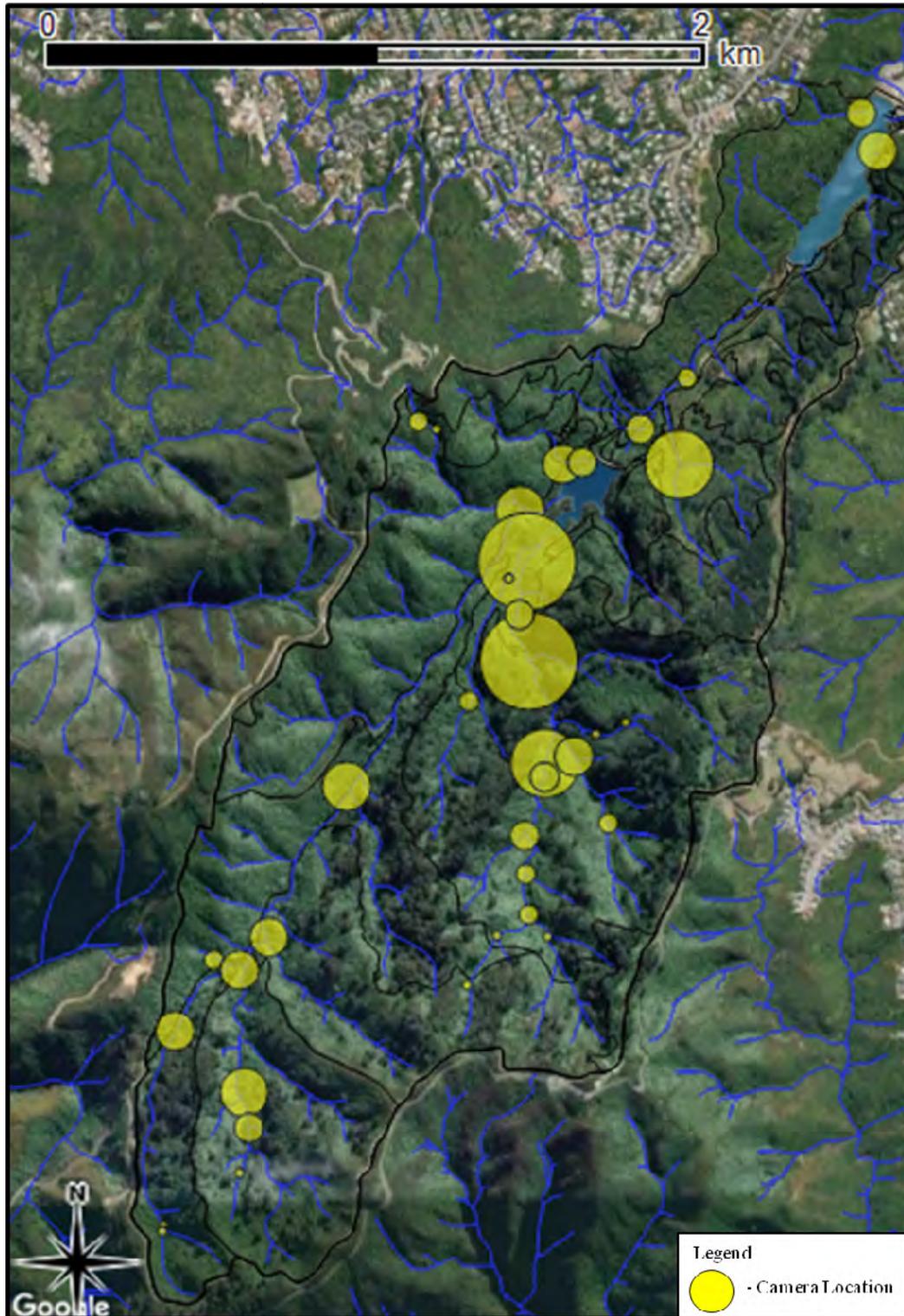
Figure 4-11. Foraging density of pāteke at Zealandia. Increase in circle size correlates to increase in number of pāteke seen at each of the 43 camera locations.

4.4.3 *Foraging frequency*

The proportion of "pāteke hours" to "camera hours" was calculated for each of the 144 camera locations. Of the 144 camera locations, 50 were found to have no pāteke observations. The highest proportion of pāteke hours captured at a camera was 22.3% of total camera hours at camera 125, located along the west shore at the southern end of the lower lake. Other areas identified as sustaining increased activity were Te Mahanga stream between the upper and lower lakes, the flock site at the south end of the upper lake, and a long segment towards the southern half of the faultline stream.

Foraging frequency at each of the 94 camera locations where pāteke were observed is shown on the map below, with circle size increasing relative to the proportion of pāteke hours recorded relative to camera hours at each location (Figure 4-12).
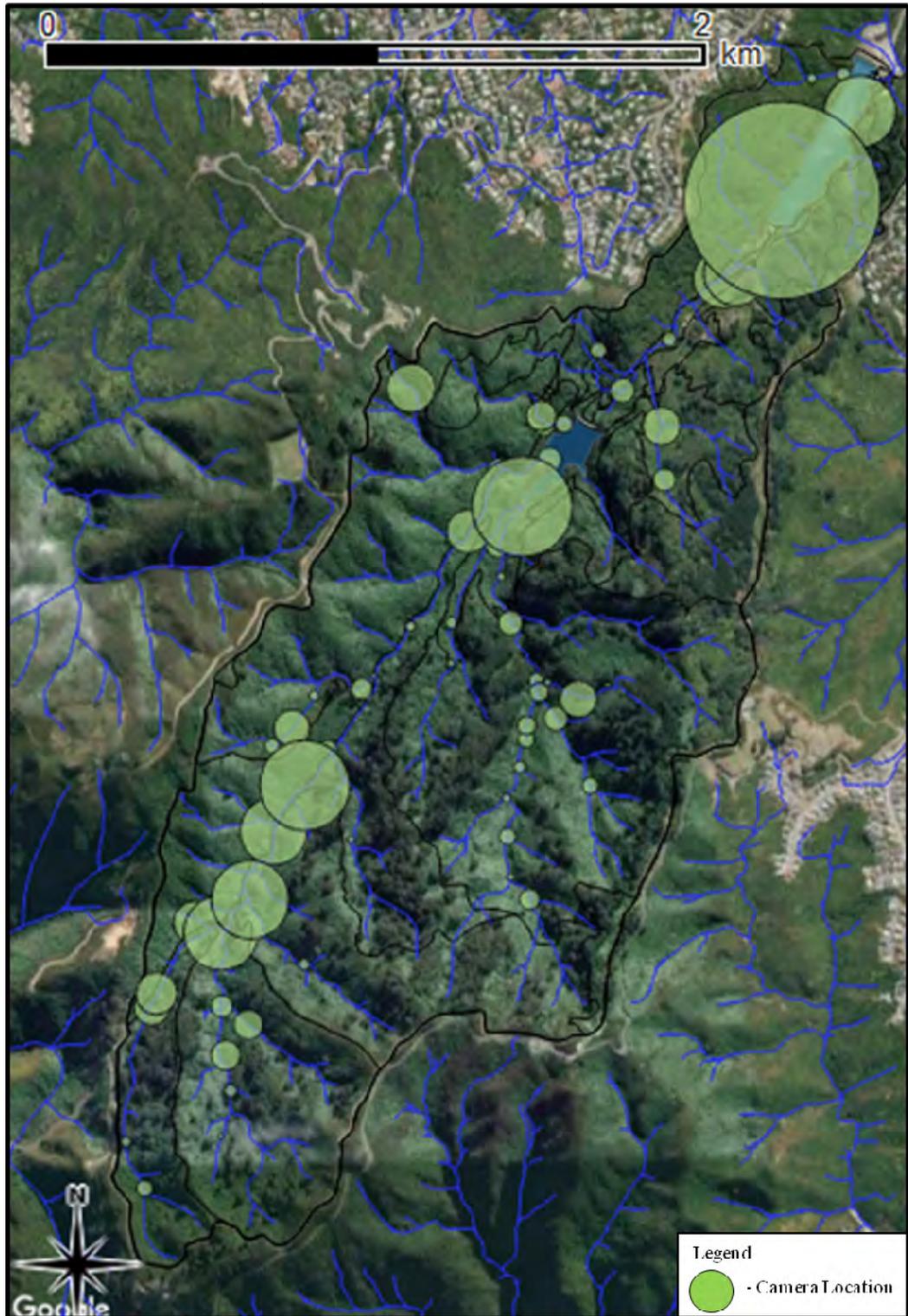
Figure 4-12. Foraging frequency of pāteke at Zealandia. Increase in circle size correlates to increase in proportion of camera hours showing pāteke to overall hours of operation of cameras at 94 camera locations.

4.5   Discussion

4.5.1   Linear foraging range

Differences in length of linear foraging range were minimal when comparing the "stream exclusive" scenario with the "hill shortcut" scenario, and did not affect the outcome of the Wilcoxon rank-sum tests between lake pāteke and bush pāteke. While there was no significant difference in the size of foraging ranges between these two scenarios, "hill shortcut" distances were slightly shorter for all three of the birds that may have used them. If they did indeed use these shortcuts, the phenomenon of crossing over hills to get to neighboring streams may be a tactic used by pāteke to conserve energy, travelling shorter distances to access food-rich corridors. This may also be indicative of pātekes' retention of the ability to forage along a terrestrial substrate, a behavior which was observed briefly on a few occasions. Use of hill shortcuts as opposed to travelling downstream to the fork and then back upstream the adjacent stream may also play a role in minimizing overlap of foraging ranges of non-paired birds, thus also reducing energy expended in defending resources.

For both the "stream exclusive" and "hill shortcut" scenarios, lake pāteke tended to maintain markedly shorter linear foraging ranges than bush pāteke, although the difference in lengths between the two groups did not meet the threshold of statistical significance in either case (P = 0.183). For each scenario, mean lake pāteke linear foraging range was less than half that of mean bush pāteke foraging range. It is important to note that this evaluation was conducted for the purposes of determining overall foraging range and that these results do not necessarily correlate with the mean distance that lake pāteke and bush pāteke travel on a nightly basis, although it is

possible that a correlation exists. To confirm such a correlation would require far more intensive night telemetry.

One potential explanation for the difference in foraging range sizes could be that food resources are more concentrated along lake edges than they are along stream corridors and so lake pāteke need not travel as far to fulfill their food requirements. A second potential explanation could be that only certain food-rich stream sections are actually being used for foraging, while the remaining sections of stream are used only as travelling corridors to access food-rich locations or other important places such as roost sites or the flock site. This explanation seems plausible when considering the distances travelled by bird 8 and bird 10 when accessing the flock site from their southern core areas. Moreover, while pāteke were observed to be foraging in many of the videos, there were a number of videos in which pāteke were not foraging and were moving at a faster pace, suggesting navigation as the primary use of the corridor.

Evaluation of linear foraging range composition revealed that the proportion of linear lake edge foraging to overall linear foraging range was significantly greater for lake pāteke than for bush pāteke (P = 0.017). The primary factor affecting lake edge foraging proportions between lake pāteke and bush pāteke is the stark difference in stream foraging range sizes between groups, the purported explanations for which are discussed above. However, bush pāteke did tend to utilize smaller lake edge sections for foraging than did the lake pāteke.

Five of the seven transmittered bush pāteke utilized lake edge to forage to some extent. Four of these five birds limited themselves to lake edge within the flock site, which provides access to the east main stream and the short section of adjoining lake edge which provides access to the west main stream. On numerous occasions, bird 5

accessed a stream feeding into the northwest corner of the upper lake, diagonally across the lake from the flock site, explaining the greater amount of lake edge used in his case.

4.5.2   *Foraging density*

Because cameras recorded in grayscale and pāteke did not always show their banded (or unbanded) legs in the video, individual identification for every pāteke video was impractical. Rather, birds were only counted as an individual if they could not possibly be any other bird observed from any other videos at that camera location. Thus, for all cameras locations, the pāteke density shown in Figure 4-11 represents the minimum number of pāteke observed to utilize the corridor, but the actual number is potentially larger.

A camera positioned proximate to the east main stream mouth leading into the flock site showed that at least 10 different pāteke utilize this stream corridor for foraging. A second camera located approximately 260 meters upstream from here, just before the first stream fork, also showed that at least 10 different pāteke utilized the corridor for foraging. Perhaps unsurprisingly, the main stream corridor leading out of the communal roost site (flock site) was the corridor used by the greatest number of pāteke.

While this analysis tells us the minimum number of birds that traversed a given corridor over the total amount of time a given camera was in operation, it does not indicate the amount of time elapsed between individual observations. Nearly always, birds were observed to be foraging by themselves, or with a mate. Time elapsed between unpaired bird observations ranged from less than one hour to several weeks. On rare occasions however, unpaired pāteke were observed on camera to be foraging

at the same location at the same time. Notably, on the few occasions where unpaired birds were seen on camera overlapping proximate to the flock site, no aggression was displayed. This is in stark contrast to the heightened displays of aggression observed on the few occasions where birds were seen on camera overlapping at far upstream feeder and non-feeder locations. This suggests that pāteke are more tolerant of communal feeding in areas where communal behavior is the norm. It could also suggest that food resources are more abundant close to the flock site and so resource defense is not necessary.

Nearly all of the first order streams within Zealandia were utilized by between zero and two pāteke. In cases where two birds were observed, they were paired with one another. Amount of overlap generally increased with proximity to the flock site and with the order of the stream, with a large section of the faultline stream readily utilized by four different adult pāteke. Greater overlap along higher order streams is likely due to their use as travelling corridors to the flock site or to adjacent lower order streams.

4.5.3   Foraging frequency

The proportion of "pāteke hours" to "camera hours" was used as a measure of estimating foraging frequency at each of the 144 camera locations. While the vast majority of pāteke videos identified the birds in the act of foraging, some videos showed only that they were travelling past that location, suggesting that section of the stream was being used as a navigational corridor. It is not entirely clear to what extent some corridors were used for travel as opposed to foraging, or whether this varied seasonally or even daily. Other videos suggested that the bird(s) used a given location primarily for roosting. While this occurrence was rare across the overall body of data,

it was clear that the location monitored by the camera at the southeast corner of the lower lake north of the pontoon steps was used most frequently for roosting.

Of the 144 camera locations, 50 were found to have no pāteke observations. The 50 camera locations were scattered throughout the valley streams and did not necessarily imply pāteke absence from specific areas. In many cases, pāteke video absence was likely due to the short duration of time in which the camera was in operation and/or coincidental absence of pāteke during the cameras' operation periods. Numerous "absence camera locations" were locations in which pāteke had been tracked using telemetry, or where cameras slightly upstream and downstream had both captured pāteke footage.

The greatest foraging frequency recorded at a camera was 22.3% of total camera hours at camera 125, located along the west shore at the southern end of the lower lake. Upon review of footage, it was confirmed that pāteke were in the act of foraging (not travelling or roosting) for nearly all of these videos. Because the camera operated for less than 500 hours (a total of only 380 hours) in this location, it was not included in the foraging density analysis. However, at least four different birds were seen foraging in this location in the 3.5 weeks the camera was in operation. This would suggest that the lake edge in this location, proximate to the mouth of a stream, is an ideal foraging locale and may be a bountiful food source for pāteke. One other location along the eastern lower lake edge, as well as two locations within the adjacent manmade wetlands area to the south also proved to have a high rate of foraging.

Unsurprisingly, the stream leading out of the flock site had a very high foraging frequency, where individuals were nearly always observed in the act of foraging (as

opposed to roosting or travelling). Many birds roosted at the flock site during the day, and then began foraging around dusk up the east main stream to access more remote tributaries. Logistically, this location would be expected to have a high proportion of pāteke footage merely from a navigational aspect, since it provides access to many of the south-eastern tributaries. However, the fact that most pāteke videos in this location showed birds foraging suggests that food in this location was abundant.

Moving away from the lakes and into the bush, the four most frequently-traversed camera locations were located along an approximately 435-meter stretch of a southern section of the faultline stream. In the case of these four camera locations, the birds that were recorded were birds that typically roosted in the bush on nearby hillsides, most of whom rarely ever visited the flock site. Thus, it follows that the northern half of the faultline stream which empties into the upper lake is not as frequently travelled. It is also possible the northern faultline stream corridor is under-travelled because it terminates within the core area of a long-standing pair and does not provide access to the flock site.

While this comprehensive foraging analysis provides some insight on the frequency with which varying stream corridors were utilized by pāteke, extrapolation of other pertinent data was impractical. Due to the limited number of cameras, camera locations had to be rotated frequently and on an ongoing basis in order to collect samples of data from various locations and for various birds. This limitation eliminated the possibility of conducting a seasonal breakdown of foraging frequency. Likewise, evaluation of individual foraging frequency at various locations was impractical as data would have been greatly biased by placement and operating times of cameras.

4.5.4 Conclusions and Management Implications

Perhaps the greatest argument facing the use of forested release sites for pāteke is that these sites offer habitat that is either unsuitable or of marginal quality at best for pāteke. Once the threat of mammalian predation is removed (or greatly reduced) from any site, the next greatest threat to pāteke survival is starvation. Thus it would follow that a site's abundance of food, already a cause for concern at remnant pāteke sites, must not be further compromised by selecting new release sites containing alternate (and potentially marginal or unsuitable) habitat and food availability. However, there are potential fallacies in this line of reasoning, which I would like to address.

It is not necessarily true that food is in higher abundance at remnant pāteke sites. While food may have been abundant in these locations prior to human settlement, the landscape has since been drastically altered. Much of the surrounding native bush has been converted to pastoral fields which offer minimal biodiversity. Development and introduction of cattle have also negatively impacted wetlands quality in these areas, likely reducing the amount of aquatic food available to pāteke. That being said, much of New Zealand's bush has also undergone change. In some locations, bush was cleared for farmland or plantation use, then fell fallow and was reclaimed by the surrounding bush, resulting in lower quality regeneration. Even where native bush has been left to stand, non-native invasive flora and fauna have readily made their way in and adversely affected the quality of the forest and its wetland features. Zealandia is among the unique cases where incredible efforts are ongoing to restore and maintain native biodiversity. Some of these efforts include ongoing removal of non-native weeds and planting of native plants throughout the valley by teams of staff and volunteers. Brown trout (*Salmo trutta*) were successfully eradicated from lakes and streams while maintaining stream invertebrate richness and abundance (Pham, 2013).

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An exhaustive "bait-out" is conducted yearly to minimize the number of mice in the valley (the only remaining mammal within the fence). Numerous species of endangered native fauna (e.g., birds, reptiles, invertebrates) have also been re-introduced. Thus, habitat quality remains an important consideration for any potential future release site, but predominantly-forested locations should not necessarily be considered marginal.

Upon their population decline, pāteke persisted longest at their Northland and Great Barrier Island locations. However, this is not necessarily a result of food abundance at these sites. It is very possible that pāteke were able to persist on Great Barrier Island because fewer mammalian predators (i.e., no mustelids) were introduced to the island, thus diminishing their risk of predation. In Northland, occupancy of sites proximate to a large body of open water may have allowed quicker escape from land predators. The communal roosting pattern characteristic of these areas may have provided "safety in numbers" from predators. Northland was also among the larger sites where pāteke were most abundant even before their decline. Therefore, there is a strong possibility that selective forces other than dietary needs determined the whereabouts of the present-day remnant pāteke strongholds.

While pāteke may have been able to procure sufficient food from the various forested environments that they inhabited historically, there is concern that generations of behavior adapted for coastal occupancy have deprived pāteke of their ability to resume this forest-foraging behavior. Foraging behavior displayed by pāteke at Zealandia strongly suggests that pāteke have retained the behavioral plasticity necessary for effective forest foraging. To some extent, the 10 transmittered pāteke, their mates and their offspring were all found to forage along forested streams. Lake

bird 3 abandoned his lakeside core areas each evening in favor of foraging along streams as opposed to foraging exclusively along the lake edge.[1] Likewise, cameras positioned at the mouths of streams regularly recorded pāteke leaving the lakes at dusk to forage upstream, before returning to the lakes (and particularly the flock site) around dawn.

There has been speculation as to whether pāteke are able to adapt to an undoubtedly different forest diet after many generations of feeding within coastal areas. The work of Moore et al. (2006) suggests that pāteke are opportunistic foragers, consuming at least 78 different floral and faunal taxa within terrestrial, freshwater and marine/estuarine environments across five different sites (including Zealandia) of varied habitat. The pāteke digestive tract is also capable of altering its morphology to facilitate efficient digestion of available food (Moore & Battley, 2006). Morphological adaptations are most significant when pāteke are transitioned between fiber-poor unvaried diets consumed by captive-fed birds and fiber-rich, varied diets typically available in the wild (Moore & Battley, 2006). Nutritional value between coastal and forest diets would be expected to vary minimally in comparison with a captive diet. This suggests that pāteke have the physiological capacity to accommodate a transition from coastal to forested diets.

Retention of the physiological capacity to forage within forested habitat was clearly evident when analyzing foraging behavior of pāteke at Zealandia. To varying degrees, food found within forested streams (and likely on the forest floor) was a key dietary component for all 10 transmittered pāteke. Identification of numerous original release

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[1] On most nights, bird 3 left his lakeside roost to feed on kaka pellet crumbs dropped by kaka at a manmade feeder before foraging along streams. The kaka feeder may have created the initial draw to leave the lake roost.

birds as well as other older birds, and confirmation that these birds spent the vast majority of their observed foraging time within and proximate to the forested streams (as opposed to the lake edges) suggests that forest diet is sufficient. For the duration of the study, several birds (e.g., bird 7 and his mate, bird 8, bird 10) were observed to forage almost exclusively within forested streams and potentially forest floor, indicating that the forest diet was sufficient to maintain their health.[2]

The largest dietary hurdle that pāteke must overcome when released into primarily forested habitat is not the transition from coastal diet to forest diet, or coastal foraging behavior to forest foraging behavior. Released birds are nearly always the progeny or descendants of coastal Barrier Island birds. However, they are hatched and reared in captivity, where they are often fed a fiber-deficient diet of commercially prepared poultry mash (K. Evans & N. Hayes, pers. Comm., 2003, as cited in Moore & Battley, 2006). For the sake of practicality, captive teal are generally reared in confined environments not conducive to development of natural foraging behavior. Therefore, it is strongly advised that upon release at any site, stationary feeders be made available temporarily to supplement pāteke diet while they adapt to the change in diet composition, the new foraging behavior required of them and the increased expenditure of energy that accompanies procuring one's food in the wild (Rickett, 2010). Given that the pāteke digestive tract can take over six weeks to fully adapt to changes in diet from captive to wild (Moore & Battley, 2006), supplemental feeders should remain in place for a minimum of two months.

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[2] Based on Zealandia's records and communications with senior rangers, pāteke had on occasion been observed in far reaches of the bush many years prior, suggesting that some birds may have maintained a predominantly-forested diet for many years.

Bush pāteke are expected to expend more energy foraging than lake pāteke, given that their mean linear foraging range was more than twice that of lake pāteke. Therefore, it is even more critical that temporary supplemental feeders be made available to pāteke released at predominantly forested release sites. Given the aggressive nature of pāteke, particularly when foraging, placement of feeders must be given careful consideration. Pāteke appeared to overlap most frequently when in close proximity to the flock site, other areas close to the lakes and along higher order streams likely also used as travelling corridors. On most occasions, only one bird (or one pair) was found to regularly forage along any given first order stream. Therefore, it is recommended that temporary supplemental feeders be placed along first or second order streams to reduce competition and ensure as many pāteke have access to feeders as possible. This approach worked well in reducing or eliminating conflict when capturing and re-capturing pāteke for transmitter fitting and removal. Feeders placed along lake edges are further discouraged in areas where mallards may be present. In the two locations where lake edge feeders were used during this study, both feeders were continuously overrun by mallards, who would not allow pāteke access to the feeders. Pātekes' natural propensity for exploration upon release should enable them to readily discover remote supplemental feeders. However, feeder locations can be rotated if they remain unused. It would also be beneficial to use a feeder style that matches the style used in captivity to facilitate the bird's recognition of the feeder as such.

The findings of the foraging analysis make little indication that primarily forested environments provide an insufficient source of food for pāteke. On the contrary, forested streams proved to be an essential food source for all seven bush pāteke, and were used to varying degrees by the three lake pāteke. Zealandia's brown teal have clearly demonstrated retention of their ability to forage in a predominantly-forested

environment. Several original release birds and other older birds were confirmed to be alive and to sustain themselves almost exclusively on a diet offered within the forested streams and adjoining bush. This suggests that once certain criteria are met (e.g., predator control, suitable flock site, adequate site size, native biodiversity) primarily-forested habitats are suitable release sites for the endangered brown teal.

References

Beauchamp, G. (1999). The evolution of communal roosting in birds: origin and secondary losses. *Behavioral Ecology*, *10*(6), 675-687.

Bowker-Wright, G., Bell, B. D., Ritchie, P. A., & Williams, M. (2012). Captive breeding and release diminishes genetic diversity in Brown Teal Anas chlorotis, an endangered New Zealand duck. *Wildfowl*, *62*(62), 176-189.

Brooke, M., & Birkhead, T. R. (1991). *Cambridge encyclopedia of ornithology*. Cambridge University Press.

Burt, W. H. (1943). Territoriality and home range concepts as applied to mammals. *Journal of mammalogy*, *24*(3), 346-352.

Calenge, C. (2015). Home range estimation in R: the adehabitatHR package. *Office national de la classe et de la faune sauvage, Saint Benoist, Auffargis, France*.

Conover, M. R. (2007). *Predator-prey dynamics: the role of olfaction*. CRC Press.

Department of Conservation (DOC). (n.d.). Brown teal/pāteke. Retrieved from http://www.doc.govt.nz/conservation/native-animals/birds/birds-a-z/brown-teal-pāteke/

Department of Conservation (DOC). (2011). Attaching radio and data-storage tags to birds: Harness mounts standard operation procedure. Department of Conservation, Wellington (unpublished). DOCDM-708212.

Derrickson, S. R. (1978). The mobility of breeding Pintails. *The Auk*, 104-114.

Downes, S. (2001). Trading heat and food for safety: costs of predator avoidance in a lizard. *Ecology*, *82*(10), 2870-2881.

Dumbell, G. S. (1986). The New Zealand Brown Teal: 1845-1985. *Wildfowl*, *37*(37), 71-87.

Dumbell, G. S. (2000). *Brown teal captive management plan*. Biodiversity Recovery Unit, Department of Conservation.

Evans, K. (2015a). NZ Brown Teal Online. Reasons of Decline. Retrieved from http://www.brownteal.com/brown-teal-pāteke /reasons-of-decline/

Evans, K. (2015b). NZ Brown Teal Online. Tiritiri Matangi Island. Retrieved from http://www.brownteal.com/reintroduction-sites/tiritiri-matangi-island/

Forest & Bird (2016). Pāteke Updates from Te Henga. Retrieved from http://www.forestandbird.org.nz/node/109408

Garrott, W. G., & White, G. C. (1990). Analysis of wildlife radio-tracking data. *Academic Press, New York*, *3*(8), 3.

Gitzen, R. A., Millspaugh, J. J., & Kernohan, B. J. (2006). Bandwidth selection for fixed-kernel analysis of animal utilization distributions. *Journal of Wildlife Management*, *70*(5), 1334-1344.

Glaser, A., van Klink, P., Elliott, G., & Edge, K. A. (2010). Whio/blue duck (Hymenolaimus malacorhynchos) recovery plan.

Hayes, F. N. (2014). Status & survival of New Zealand brown teal (*Anas chlorotis*). Unpublished.

Hayes, F. N. (n.d.). Ducks Unlimited New Zealand. *Valiant efforts to save ducks from extinction.* Retrieved from http://www.ducks.org.nz/articles/article8.htm

Hayes, F. N., & Dumbell, G. S. (1989). Progress in brown teal Anas a. chlorotis conservation. *Wildfowl, 40*(40), 137-140.

Hayes, F. N., & Williams, M. (1982). The status, aviculture and re-establishment of brown teal in New Zealand. *Wildfowl*, *33*(33), 73-80.

Heather, B. D., & Robertson, H. A. (2000). *The field guide to the birds of New Zealand* (No. Revised edition). Viking\ Penguin Books.

Holdaway, R. N. (1996). Arrival of Rats in New-Zealand. *Nature, 384*(6606), 225-226.

Holdaway, R. N., Williams, M., & Hawke, D. J. (2013). A comparison of the pre-human and present isotopic niches of brown teal (Anas chlorotis): implications for conservation. *Notornis*, *60*, 233-244.

Isaac Conservation and Wildlife Trust (ICWT) (2016). Brown Teal. Retrieved from https://www.facebook.com/pg/ICWTNZ/photos/?tab=album&album_id=4094394124 94010

IUCN. (2015). *Anas chlorotis.* The IUCN Red List of Threatened Species. Retrieved from http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22728303A83275138.en

Karori Wildlife Sanctuary (2004). *Brown Teal Restoration & Experience*. Retrieved from http://www.sanctuary.org.nz/Scripts/printfriendly.php

King, C. M. (1990). The handbook of New Zealand mammals. Oxford University Press.

Knight, C. M., Kenward, R. E., Gozlan, R. E., Hodder, K. H., Walls, S. S., & Lucas, M. C. (2009). Home-range estimation within complex restricted environments: importance of method selection in detecting seasonal change. Wildlife Research, 36(3), 213-224.

McNab, B. K. (1994). Energy conservation and the evolution of flightlessness in birds. *The American Naturalist*, *144*(4), 628-642.

Mohr, C. O. (1947). Table of equivalent populations of North American small mammals. *The American Midland Naturalist*, *37*(1), 223-249.

Moore, S. J., & Battley, P. F. (2006). Differences in the digestive organ morphology of captive and wild Brown Teal Anas chlorotis and implications for releases. *Bird Conservation International*, *16*(03), 253-264.

Moore, S. J., Battley, P. F., Henderson, I. M., & Webb, C. J. (2006). The diet of brown teal (Anas chlorotis). *New Zealand Journal of Ecology*, 397-403.

Neaves, L. E., Eales, J., Whitlock, R., Hollingsworth, P. M., Burke, T., & Pullin, A. S. (2015). The fitness consequences of inbreeding in natural populations and their implications for species conservation–a systematic map. *Environmental Evidence*, *4*(1), 5.

O'Connor, S. M., Maloney, R., & Pierce, R. J. (2007). *Pāteke (Anas chlorotis) recovery plan, 2005-10*. Science & Technical Pub., Department of Conservation.

Ouellette, M., & Cardille, J. A. (2011). The Complex Linear Home Range Estimator: Representing the Home Range of River Turtles Moving in Multiple Channels. *Chelonian Conservation and Biology*, *10*(2), 259-265.

Parker, K. A. (2013). Avian translocations to and from Tiritiri Matangi 1974 – 2013. *New Zealand Journal of Ecology, 37*(3). 282.

Parkes, J., & Murphy, E. (2003). Management of introduced mammals in New Zealand. *New Zealand Journal of Zoology, 30*(4), 335-359. http://dx.doi.org/10.1080/03014223.2003.9518346

Pham, L. T. (2013). *Rotenone use for native fish conservation: Macroinvertebrate community recovery and the reintroduction of a native galaxiid (Galaxias fasciatus) following piscicide treatment in two streams* (Doctoral dissertation, University of Otago).

Poole, K. G. (1995). Spatial organization of a lynx population. *Canadian Journal of Zoology*, *73*(4), 632-641.

Powell, R. A., & Mitchell, M. S. (2012). What is a home range?. *Journal of Mammalogy*, *93*(4), 948-958.

QGIS Development Team, 2009. QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.osgeo.org

R Core Team. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rattenborg, N. C., Lima, S. L., & Amlaner, C. J. (1999). Facultative control of avian unihemispheric sleep under the risk of predation. *Behavioral brain research*, *105*(2), 163-172.

Reid, B., & Roderick, C. (1973). New Zealand scaup Aythya novaeseelandiae and Brown teal Anas aucklandica chlorotis in captivity. *International zoo yearbook*, *13*(1), 12-15.

Rickett, J. (2010). *The dispersal and survivorship of pāteke (Anas chlorotis) in relation to experimental release techniques; supplementary feeding and wing-clipping: a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Conservation Biology, Massey University, Auckland* (Doctoral dissertation, Massey University).

Ridout, M. S., & Linkie, M. (2009). Estimating overlap of daily activity patterns from camera trap data. *Journal of Agricultural, Biological, and Environmental Statistics*, *14*(3), 322-337.

Ringelman, J. K., Longcore, J. R., & Owen Jr, R. B. (1982). Breeding habitat selection and home range of radio-marked black ducks (Anas rubripes) in Maine. *Canadian Journal of Zoology*, *60*(2), 241-248.

Rowcliffe, J. M., Kays, R., Kranstauber, B., Carbone, C., & Jansen, P. A. (2014). Quantifying levels of animal activity using camera trap data. *Methods in Ecology and Evolution*, *5*(11), 1170-1179.

Stamps, J. A. (1994). Territorial behavior: testing the assumptions. *Advances in the Study of Behavior*, *23*, 173-232.

Weller, M. W. (1974). Habitat selection and feeding patterns of brown teal (Anas castanea chlorotis) on Great Barrier Island. *Notornis*, *21*, 25-35.

Williams, M. J. (1969). Brown teal released on Kapiti Island. *Notornis, 16*(1), 61.

Williams, M. J., & Dumbell, G. S. (1996). *Brown teal (pāteke)* Anas chlorotis *recovery plan*. Department of Conservation, Threatened Species Unit.

Worthy, T. H. (2002). *Fossil distribution of brown teal (Anas chlorotis) in New Zealand* (p. 29). Department of Conservation.

Worthy, T. H., & Holdaway, R. H. (2002). Prehistoric life of New Zealand. The lost world of the Moa (p. 718). Christchurch, Canterbury University Press.

Worton, B. J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. *Ecology*, *70*(1), 164-168.

Worton, B. J. (1995). A convex hull-based estimator of home-range size. *Biometrics*, 1206-1215.

Zealandia: Te Māra a Tāne, (n.d.). Home Page. Retrieved from https://www.visitZealandia.com/About/The-History/A-World-First-Sanctuary

Appendices

Appendix 1 – Victoria University of Wellington Animal Ethics Committee

Application and Approval

VICTORIA UNIVERSITY OF WELLINGTON

**ANIMAL ETHICS COMMITTEE APPLICATION
FOR USE OF LIVE ANIMALS**

1. Department or School: City University of New York at Queens College, Biology Department

2. Research/ (delete one). Course Code __BIOL 7996

3. Title of project: Are fenced forest sanctuaries unappreciated conservation sites for the endangered brown teal?

4. Estimated duration of project: (If on-going, maximum approval period is 3 years)

   Field activities associated with this project are expected to commence on September 15, 2013 and be completed by May 10, 2015.

5. Personnel, Qualifications, & Experience:

   (a) Principal Investigator: (must be academic staff of grade lecturer or above)

   Katie Sheridan, BS Environmental Biology; current Masters student at CUNY Queens College, USA; Full-time intern at Zealandia, January - May 2013, current part-time volunteer at Zealandia. Experience using telemetry to track kakariki. Some banding experience with small passerines.

   (b) Co-Investigators: (Include qualifications and experience)

   Raewyn Empson Conservation Manager, Zealandia-Karori Sanctuary
   Richard Gray, Matu Booth, and Brian Ireland – staff at Zealandia-Karori Sanctuary
   Joanna Sim, Ecologist and Specialized pateke search dog handler
   All but Brian Ireland have experience in attaching transmitters to birds.

   (c) Student/Technical assistants: (Include qualifications and experience) (List training procedures planned)

   Katie Sheridan (Principal Investigator) - Additional banding experience will be undertaken prior to commencement of field activities. If warranted, training will be undertaken for affixing backpack harness-mounted transmitters/GPS tags and/or tail-mounted transmitters. All transmitters/GPS tags will be affixed by an individual approved by the New Zealand Department of Conservation.

   (d) List project funding: (List all agencies from which funding has been received for this project)

   Karori Sanctuary Trust, through private donations.

6. State where animals will be housed, who will care for them, how they will be maintained, and who will carry out anaesthesia, surgery and euthanasia: (refer Code 5 viii, x)

   They are wild birds and will not be housed in captivity.

7. Lay summary: (Short paragraph for non-scientists; will be made available to the general public)

   The main objective of this project is to determine whether fenced, forested sanctuaries provide suitable habitat for pateke. To achieve this, we will evaluate several aspects of behavior and habitat use of a population of primarily forest-dwelling pateke that reside within the fenced Karori Wildlife Sanctuary. Upon capture, individual teal will be measured, weighed and banded. Feather and blood samples will be collected for potential future analysis by other researchers. Patterned reflective tape will be affixed to bands after banding the pateke, in order to facilitate identification at night. Transmitters will be affixed to up to 30 pateke (15 males and 15 females) from both open water areas and forested areas. These individuals will be monitored using aerial telemetry. By tracking these individuals, roosting sites, foraging pathways, territory sizes and locations can be established. Once roosting sites

are determined, fixed motion-sensing cameras will be placed to record activities, ingress and egress from the roosting sites and will also be placed along traveling/foraging paths to monitor activity. Pending approvals and funding, one GPS unit would be affixed to various pateke, if possible, throughout the duration of the project to ascertain a more accurate depiction of individual range, territory size, and roosting and foraging patterns. Project field activities are anticipated to commence on September 15, 2013 and are anticipated to be completed by May 10, 2015. If it is determined that fenced forests provide suitable habitat for pateke, the number and distribution of future release sites would be greatly improved, thus facilitating conservation of the species.

8. **Background, aim and significance of project:** (Maximum of one page) *(refer Code, Sections 5 ii, iv, v)*

Brown teal (pateke) conservation is concentrated in lowland pastoral areas in eastern North Island. Fossil brown teal distribution implies teal once lived in small waterways deep within forests. I seek evidence that forests fenced to exclude mammals offer sites in which teal populations can be established and thrive as they did prior to human settlement. This project will evaluate the teal population that has persisted within the fenced and predominantly forested Zealandia-Karori Sanctuary since their release in 2000. Population size, distribution, territory sizes and spatial relations, and spatial and temporal foraging and roosting patterns will be investigated. Specially trained dogs, radio transmitters, GPS tags, bands, fixed motion-sensing cameras and direct observation (daytime and night-time) will be used to locate teal and evaluate the nature and extent of forest habitat use within the parameters described above. Findings can then be used as a basis for comparison to parallel parameters demonstrated by pateke that populate primarily low-lying pastoral habitats. This investigation will be the subject of a Master's thesis. A synopsis of this study will be submitted for publication in a scientific journal. A report will be made available to the Karori Sanctuary Trust and the Brown Teal Recovery Group.

9. **Give the species, strain, sex, age, and source of animals, and state the total number of each species needed for the project.** *(refer Code 5vii)*

Pateke, Brown Teal (*Anas chlorotis*).
All captured pateke will be banded and measured and will have blood and feather samples collected, so as to ascertain the current population size and facilitate future monitoring and research of pateke at Zealandia. Transmitters will be affixed to up to thirty adult individuals, ideally including 15 males and 15 females. GPS tags may be affixed to adult males and females, and to any juveniles who exceed 450 grams, as per DoC regulations. As a conservative estimate, up to 25 individuals may be fitted with a GPS tag, although this number will likely be lower, given the difficulty with which pateke (particularly forest-dwelling individuals) are located and captured.

10. If your project requires DOC approval, please tick here: X DOC Ref. No. Application to be submitted shortly

11. **Justification of animal use - Explain why the proposed use of animals is desirable, what alternative approaches are available, and how the number of animals used will be minimised.** (State prior history of animals, and provide statistical or biological justification of numbers.) *(refer Code 5i, ii, iii)*

Given that pateke are a particularly shy bird, and as they are nocturnal, they are very difficult to monitor through direct observation alone. This difficulty is compounded for the individuals within the more remote forested parts of the sanctuary. The most realistic and previously successful method of gaining accurate data on individual territory size, range, and identification of roosting sites and foraging paths is through the use of VHF transmitters. By using up to 30 individuals in the VHF transmitter portion of the study, we can document the extent of variation in territory sizes and range, and gain a more comprehensive base of knowledge pertaining to intraspecific interactions, roosting and foraging patterns, and territory sizes and ranges. Further, by being able to identify specific roosting and foraging locations, we can assess habitat composition and possibly identify individual food preferences. We can also identify specific locations for staging fixed motion-sensing cameras to capture footage of roost site behavior and foraging behavior.

12. **Details of animal manipulation:**

(a) **Pain classification of project:** (Please indicate the grade(s) of your manipulation(s): Grade A – no impact; Grade B – little impact; Grade C – moderate impact; Grade D – high impact; Grade E – very high impact. Give justification for your choice of grade)

Grade B. The birds are subject to the stress of capture and being restrained for about 20 minutes. However, to date, capture and handling of pateke within the sanctuary (for banding purposes and to affix backpack harness-mounted transmitters) has not had any observable adverse effects.

(b) **Experimental design of project:** (give overall design, including specific details of protocols involving animals, including details of experimental and control groups of animals, and state if method to be used is

standard practice or a new approach. If applicable, give details of risk management and containment procedures.) *(refer Code 5 iii, vi)*

In easily accessible areas, Pateke will be captured using cage traps and/or call playback and hand nets. Cage traps would be checked within 12 hours of being set so as to minimise the amount of time individuals are trapped. This method of catching pateke has previously been used successfully within Zealandia. Where use of cage traps is impractical due to steep terrain and remote location, a specially trained pateke search dog and hand nets will be used to capture the pateke. Joanna Sim owns a specially trained pateke search dog and has experience working with this dog to locate and capture pateke.

Each captured pateke will be measured and banded. Patterned reflective tape will be affixed to each coloured band in order to facilitate identification at night. Blood and feather samples will be collected from each individual for use in potential future research. In addition, ten tail-mounted VHF transmitters will be attached to a total of thirty adult pateke, which will be monitored in three rounds. Pateke used will be a combination of open water-dwelling and forest-dwelling pateke. The first round of ten pateke (five males and five females) will be monitored for four months. The second and third rounds of monitoring will include five males and five females each, which will be monitored in two three-month periods. Individuals will be restrained by hand for about 15-20 minutes while the transmitter is attached to two central tail feathers, following the protocol in the DoC SOP for telemetry.

Use of tail-mounted transmitters on pateke may be novel. However, tail-mounted transmitters have been used on blue duck and on Auckland Island teal and Campbell Island teal with stunning success on all species. Pateke are bigger and the tail longer and more robust than both Auckland Island and Campbell Island teal but a little less so than blue duck, which for a duck of its size has quite a long tail. Tail-mounted transmitters have also been used on grey teal in Australia and on green-winged teal in the United Kingdom. As such, use of tail-mounted transmitters on pateke is not expected to have any adverse effects. Once transmitters are affixed, the bird will be released back into the wild. Tail-mounted transmitters will be removed after four months in the first round of monitoring and after three months in the second and third rounds of monitoring. In the event that a transmitted bird cannot be recaptured, transmitters will fall off once the bird has molted its tail feathers.

Finally, a backpack harness-mounted GPS tag would be affixed to individual teal for up to one month (depending on model and battery life), after which the GPS tag would be removed, recharged and affixed to another teal. Various types of backpack harness-mounted GPS tags have been trialed on pateke but have been deemed unsuitable for various reasons, usually due to units cracking and being damaged with water. The model that would likely be trialed in this project would be one of the two following Sirtrack® Micro GPS Transmitters listed below:

Model	L x W x H (mm)	Weight (g)	Life (days)*	Rechargeable	VHF
G1G 132A	43 x 32 x 24	21	10	Yes	No
G1G 134A	43 x 32 x 24	23	20	Yes	No

The GPS unit would be attached to teal in accordance with the DoC SOP - Attaching radio and data-storage tags to birds: Harness mounts. As an additional precautionary measure, backpack harnesses will contain built-in linen weak-link thread, so that the harness eventually detaches itself from the pateke in the event that it cannot be recaptured.

While this is the optimal and intended scope of work for the proposed project, some aspects of the experimental design may be altered slightly to account for variation in equipment arrival time and ease with which pateke are caught.

(c) **Anaesthesia or euthanasia procedures**: (give specific drugs, doses, and routes of administration)   *(refer Code 5 xi, xii)*

N/A

(d) **Surgical procedures**: (give details for each type of operation) *(refer Code 5 viii)*

N/A

(e) **Provisions for post-manipulation recovery and care - definitions of endpoints – whether based on humane considerations, death of animal, or aims of the study**: *(refer Code 5 x)*

N/A Should any bird be injured during this process (unlikely) veterinary advice will be sought if appropriate to ensure its recovery.

. **Fate of animals at conclusion of study**: *(refer Code 5 ix, xi)*

N/A – all will be free-ranging in the wild

14. **Proposed avenue of publication of research results:** (Results from research projects are expected to be published. For on-going projects, evidence of publication is required before approval can be given to renew the application for a further 3 years.)

Publication in scientific journal at the end of the study.

15. **An Institutional Drug Administration Order (IDAO) and Drug Data Sheets (DDS) are needed and are attached to this application.**

NO (Not Needed)

DECLARATION BY APPLICANTS

I am aware that this project is undertaken within the provisions of the Animal Welfare Act 1999, I have read the Victoria University of Wellington Code of Ethical Conduct for the Use of Live Animals for Teaching and Research, and I agree to abide by all the conditions contained in these two documents. In the event of this application being approved, I will promptly inform the Animal Ethics Committee of any subsequent unforeseen changes or planned modifications to the project, giving explanations for all such changes. I agree to maintain accurate records of all animals used (*refer Code, Section 4 (c)*) and to make these records available promptly to the Executive Officer of the Animal Ethics Committee.

Date: 04/06/13

Signature of Head of School: _____ Date: _____

Please Return the Completed Form to the Executive Officer, A. E. C.
(J. H. Miller, School of Biological Sciences)

Version 1.2010   ***** END *****

VICTORIA UNIVERSITY OF WELLINGTON

ANIMAL ETHICS COMMITTEE

June 13, 2013

Memorandum to: Ms Katie Sheridan
                Zealandia Wildlife Sanctuary

Cc Raewyn Empson

Re: Evaluation of AEC application:

> **2013R11   Are fenced forest sanctuaries unappreciated conservation sites for the
> endangered brown teal?**

Your application to use live animals in your research at the Malaghan Institute was approved by the AEC at its meeting on Tuesday June 11th, 2013. Approval is given for a period of 2 year as requested (expiration date July 1, 2015). Should you wish to extend your approval beyond this time, a letter requesting an extension that states the reason for the extension should be forwarded to the Committee.

We thank you for your cooperation in helping the Committee ensure appropriate animal welfare standards and procedures are in place at Victoria University.
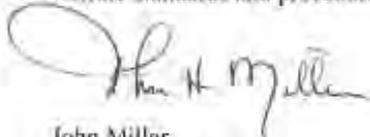
John Miller
AEC Executive Officer
School of Biological Sciences

Appendix 2 – New Zealand Department of Conservation Wildlife Act

Authority Application Approval

Department of Conservation
Te Papa Atawhai

File Ref:

10 October 2013

Sheridan, Katie

Mount Cook
Wellington 6011
New Zealand

For the attention of: Katie Sheridan

Dear Katie Sheridan

Re: WILDLIFE ACT AUTHORITY APPLICATION 36853-FAU APPROVAL

I am pleased to advise you that your application for a Wildlife Act Authority has been approved and I am now able to offer you an authority outlining the terms and conditions of this approval. Please find the authority enclosed.

This document contains all the terms and conditions of your authorisation to operate on non public conservation land and represents the formal approval from the Department for Sheridan, Katie to carry out the activity.

Payment of Processing Fees
Please advise when you have completed the direct credit which was organised on the 10th of October 2013 .

Kind regards,

Jess Mason
Permissions Advisor
Hamilton Shared Services
Private Bag 3072
Hamilton 3240

File Number: 36853-FAU

THIS AUTHORITY is made this 8th day of August 2013

PARTIES:

The Director General of Conservation (the Grantor)

Katie Sheridan (the Authority Holder)

BACKGROUND

A. The Director General of Conservation is empowered to issue authorisations under the Wildlife Act 1953.

B. The Authority Holder wishes to exercise the authorisation on the Land subject to the terms and conditions of this Authority.

OPERATIVE PARTS

In exercise of the Grantor's powers under the Conservation legislation the Grantor **AUTHORISES** the Authority Holder under Section 53 of the Wildlife Act 1953 subject to the terms and conditions contained in this Authority and its Schedules.

SIGNED on behalf of the Grantor

by Carol West

....
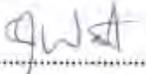
Manager, Terrestrial Ecosystems

Kaihautū Kāhui Hangarau-Pūtaiao

acting under delegated authority
in the presence of:

Witness Signature: _____

Witness Name: _Grannah Aitken_

Witness Occupation: _PA_

Witness Address: _81 Wallace St_

A copy of the Instrument of Delegation may be inspected at the Director-General's office at 18-22 Manners Street, Wellington

SCHEDULE 1

1.	*Authorised activity (including approved quantities of wildlife and collection methods).* (clause 2)	The capture of Pateke (*Anas chlorotis*) In easily-accessible areas, cage traps will be used to catch teal. These cages have previously been used successfully at Zealandia to catch teal. Preliminary surveys with fixed motion-sensing cameras will be conducted to determine the most suitable time to catch teal in a specific location. Cage traps would then be set in the location at the appropriate time and then checked shortly thereafter so as to minimise time teal are trapped. In more remote locations, a specially-trained and experienced pateke search dog (with handler) will be used to locate the teal. Once located, teal would be caught with hand nets and/or seine-like nets.
		Band / tag / mark / apparatus to be fitted	Method
		Metal bands (size S) and colour bands (size S)	S metal bands will be placed on the teal's tarsus with banding clamps. 10mm diameter wrap-around colour bands will be placed on the teal's tarsus. Patterned and coloured reflective tape will be affixed to bands to facilitate identification at night.
		VHF Transmitters and Harnesses	Backpack harness-mounted VHF transmitters would be fitted to individual teal, following the methods set forth in the DoC SOP "Attaching radio and data-storage tags to birds: Harness mounts". Harnesses would be equipped with built-in polyester weak-link thread so that the harness would eventually detach itself in the event that the teal cannot be recaptured.
2.	**The Location** (clause 2)	All pateke will be caught within Zealandia – Karori Wildlife Sanctuary (41° 28' S, 174° 44' E). This is the ideal location for my research because it contains a population of pateke persisting within a forested habitat that is fenced to exclude mammalian predators.
3.	**Authorised Personnel** (clause 3)	MA Student and Principal Investigator: Katie Sheridan Supervisor: Raewyn Empson Technical Advisor: Murray Williams Tracking Dog Handler: Joanna Sim (or other dog and handler approved by DoC) Co-Investigator: Neil Anderson Various other staff and volunteers at Zealandia may assist with monitoring pateke.

2

4.	**Term** (clause 4)	Commencing on and including *01 September 2013* and ending on and including *31 May 2015*
5.	***Authority Holder's address for notices*** (clause 8)	The Authority Holders address in New Zealand is: 94 Rolleston Street, Mount Cook Wellington 6011 New Zealand Phone: 0279503871

SCHEDULE 2

STANDARD TERMS AND CONDITIONS OF THE AUTHORITY

1. **Interpretation**

1.1 The Authority Holder is responsible for the acts and omissions of its employees, contractors or, agents. The Authority Holder is liable under this Authority for any breach of the terms of the Authority by its employees, contractors or agents as if the breach had been committed by the Authority Holder.

1.2 Where obligations bind more than one person, those obligations bind those persons jointly and separately.

2. **What is being authorised?**

2.1 The Authority Holder is only allowed to carry out the Authorised Activity in the Location(s) described in Schedule 1, Item 2.

2.2 The Authority Holder must contact the Department of Conservation's local Conservation Partnerships Manager(s) prior to carrying out the Authorised Activity in the Area.

2.3 The Authority Holder must obtain land owner approval before exercising this Authority

2.4 The Authority Holder and Authorised Personnel must carry a copy of this Authority with them at all times while carrying out the Authorised Activity.

2.5 Unless expressly authorised by the Grantor in writing, the Authority Holder must not donate, sell or otherwise transfer to any third party any material, including any genetic material, or any material propagated or cloned from such material, collected under this Authority. Notwithstanding the preceding constraint, the Authority Holder may publish authorised research results.

2.6 The Authority Holder must lodge holotype specimens and a voucher specimen with a recognised national collection any taxon, which is new to science. The Authority Holder must immediately notify the Grantor of any such finds.

3. **Who is authorised?**

3.1 Only the Authority Holder and the Authorised Personnel described in Schedule 1, Item 3 may be involved in carrying out the Authorised Activity, unless otherwise agreed in writing by the Grantor.

4. **How long is the Authority for - the Term?**

4.1 This Authority commences and ends on the dates set out in Schedule 1, Item 4.

5. What are the liabilities?

5.1 The Authority Holder agrees to exercise the Authority at the Authority Holder's own risk and releases to the full extent permitted by law the Grantor and the Grantor's employees and agents from all claims and demands of any kind and from all liability which may arise in respect of any accident, damage or injury occurring to any person or property arising from the Authority Holder's exercise of the Authorised Activity.

5.2 The Authority Holder must indemnify the Grantor against all claims, actions, losses and expenses of any nature which the Grantor may suffer or incur or for which the Grantor may become liable arising from the Authority Holder's exercise of the Authorised Activity.

5.3 This indemnity is to continue after the expiry or termination of this Authority in respect of any acts or omissions occurring or arising before its expiry or termination.

6. What about compliance with legislation and Grantor's notices and directions?

6.1 The Authority Holder must comply with all statutes, bylaws and regulations, and all notices and requisitions of any competent Authority relating to the conduct of the Authorised Activity. Without limitation, this includes the Conservation Act and the Acts listed in the First Schedule of that Act and the Health and Safety in Employment Act.

6.2 The Authority Holder must comply with all reasonable notices and directions of the Grantor relating to the conduct of the Authorised Activity.

7. When can the Authority be terminated?

7.1 The Grantor may terminate this Authority at any time in respect of the whole or any part of the Land if:

(a) The Authority Holder breaches any of the conditions of this Authority; or

(b) in the Grantor's opinion, the carrying out of the Authorised Activity causes or is likely to cause any unforeseen or unacceptable effects

7.2 If the Grantor intends to terminate this Authority, the Grantor must give the Authority Holder either:

(a) one calendar month's notice in writing; or

(b) such other time period which in the sole opinion of the Grantor appears reasonable and necessary

8. How are notices sent and when are they received?

8.1 Any notice to be given under this Authority by the Grantor is to be in writing and made by personal delivery, fax, by pre paid post or email to the Authority Holder at the address, fax number or email address specified in Schedule 1, Item 5. Any such notice is to be deemed to have been received:

(a) in the case of personal delivery, on the date of delivery;

(b) in the case of fax, on the date of dispatch;

(c) in the case of post, on the 3rd working day after posting;

(d) in the case of email, on the date receipt of the email is acknowledged by the addressee by return email or otherwise in writing.

8.2   If the Authorised Holder's details specified in Schedule 1, Item 5 change then the Authorised Holder must notify the Grantor within 5 working days of such change.

9. **What about the payment of costs?**

9.1   The Authorised Holder must pay the standard Department of Conservation charge-out rates for any staff time and mileage required to monitor compliance with this Authority and to investigate any alleged breaches of the terms and conditions of it

10. **Are there any Special Conditions?**

10.1   Special conditions are specified in Schedule 3. If there is a conflict between this Schedule 2 and the Special Conditions in Schedule 3, the Special Conditions shall prevail.

SCHEDULE 3

SPECIAL CONDITIONS

1.   The permit holder will engage with Ngatiwai on a meaningful basis including technical participation.

2.   A copy of the report that is required to be provided to The Department of Conservation should also be forwarded to Ngatiwai at the completion of the research, the permit holder shell forward a 1-2 page "laypersons" account of the research findings to Ngatiwai Trust Board.

3.   All banding must be done under the direct supervision of Raewyn Empson

Appendix 3 – Karori Wildlife Sanctuary Trust Contract to Undertake Research

KARORI WILDLIFE SANCTUARY TRUST
Contract for admission to the Sanctuary to undertake research

Research Pass Number: 27

Issued to: Katie Sheridan

Start Date: 7/1/13

Finish Date: 28/2/15

Access is permitted and a research pass issued on the following conditions:

RESEARCH PROJECTS.

Access will be allowed only between the dates specified in the research proposal.

If an extension is required, a written request should be made to the Conservation Manager (raewyn@sanctuary.org.nz) at least 14 working days prior to the end date specified in the proposal.

If any changes are proposed to the research programme as detailed in the application form, a written request should be made to the Conservation Manager before any change can be effected.

LIMIT OF ACCESS.

Access is allowed only for the purpose of research so your research pass may only be used for this purpose. One additional person may accompany you as an assistant. Recreational access for family and friends is not allowed.

SAFETY & COMMUNICATIONS:

The Sanctuary is a natural area and as such there are hazards. You are responsible for your safety. You are required to follow the rules in the attached "Golden Rules" when working in the Sanctuary, and must not enter any closed tracks or areas closed during gale-force winds. To check if any tracks are closed, contact the Duty officer ph 0276345454 at weekends or Russ ph 0277333731 during the week;

After hours you must be accompanied by an able assistant, and have a "buddy" arrangement' (see Golden Rules) who will report you missing to the 24hr emergency number if you fail to return by the expected time.

You are responsible for your safety and that of your assistant. This means that both of you must wear boots with good ankle support as you will be working off-track, and your cell phone is to be carried at all times while in the valley.

KARORI WILDLIFE SANCTUARY
TELEPHONE NUMBERS

EMERGENCY CALL CENTRE
04 4716870
Main Office (bus hours) 920 9200
Raewyn Empson (bus.hrs) 920 9215

INTENTIONS:

When you enter the valley you are to register at the tearoom beside the Ops shed, note your cellphone number and expected completion time, and sign out when you leave so you are not regarded as a missing person. The tearoom is open from 8:00 am to 5:00 pm.

FIRES AND RUBBISH:

A permanent fire ban is in force in the Sanctuary. Smoking is only permitted outside the sanctuary in designated areas. You must carry-out all your rubbish.

KEY:

If you have a key you must ensure that you lock all gates that you have unlocked at all times.

RESEARCH FINDINGS:

Any KWS data used in this research must be appropriately acknowledged and/or any collaborative work jointly published by agreement.

Depending on the scope of the research, interim reports, signage and presentations to sanctuary visitors, staff and volunteers may be required.

A 2 page summary of research objectives and findings suitable for placement on the Trust's website is required.

A copy of any reports or publications arising out of any approved research are to be provided to the Karori Sanctuary Trust.

A copy of any thesis that has been approved and undertaken is to be provided to the Karori Sanctuary Trust.

I _____*Katie A. Sheridan*_____
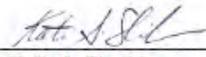
Katie A. Sheridan

certify that the information provided on the application form and attached information is to the best of my knowledge true and correct; and I will :

- liaise with the Conservation Manager regarding any changes to the proposed research before any modifications are effected;
- liaise with the Conservation Manager if any extension is required giving at least 14 working days notice;
- agree to the conditions of this contract regarding research findings as above.

Dated: ___26/2/14___