Behaviour and Activity Budgeting of Reproductive Kiwi in a Fenced Population

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Abstract

North Island brown kiwi (*Apteryx mantelli*) are flightless, nocturnal, usually solitary, and secretive birds, so knowledge of their behaviour is limited. In this study, I endeavoured to obtain a more detailed understanding of adult kiwi behaviour within two pest fenced areas focusing around the breeding season at the 3363 ha Maungatautari Scenic Reserve in Waikato, New Zealand. Within Maungatautari's pest free enclosures, I attempted to determine male and female activity patterns over 24-hours from activity transmitter data; document diurnal and nocturnal behaviours of kiwi using video cameras; determine size and distribution of home ranges; and establish patterns of selection of daytime shelter types. Male kiwi were fitted with Wild Tech "chick timer" transmitters which recorded activity for the previous seven days. Incubating males spent significantly less time active than non incubating males with some activity occurring during the daytime. Non-incubating male activity duration decreased but activity as a proportion of night length increased with decreasing night length. Less active incubating males, suggesting more time caring for eggs, had more successful clutches. Female activity was recorded using an Osprey receiver/datalogger and 30x60x90 pulse activity transmitters. Proportional activity was not correlated with night length and some female kiwi had extensive activity during the day which likely involved leaving their shelters. The occurrence of post-dawn activity was highly likely due to prior knowledge of feeding conditions. Efforts to obtain video footage of kiwi were only possible during daytime in shelters. Kiwi mostly slept during the day but they also scratched, stretched, preened, excavated, defecated, yawned, fed and sniffed. When a mate was present kiwi overall slept less. Mate preening was recorded for the first time. Significant differences in home range sizes were found between all male and female kiwi in both enclosures, and males and females in the southern enclosure. Home range overlap occurred only between females and unpaired birds. Shelter proximity to streams was significant, and reproductive status and water availability may be strong drivers determining home range

location for Maungatautari enclosure kiwi. Dead vegetation matter and then underground cavities were the broad shelter types most used by kiwi and at a more detailed level, Windrows. Exploited Root Systems, Downed Logs, and Downed Masses were selected. Shelters were rarely re-used most likely due to an abundance of available shelters. Access to permanent water courses should be considered when considering habitat options for new kiwi populations as it helps ensure food availability. As well, the presence of abundant coarse woody debris creates high quality habitat for sheltering. Kiwi did not appear to be negatively impacted by the size of the enclosures at Maungatautari, and the population was healthy there during the course of this study.

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And now for my Pièce de la Rèsistance…

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1.1   Biodiversity- To the brink and back

"Between 12% and 52% of species within well-studied higher taxa are threatened with extinction" (Millennium Ecosystem Assessment, 2005). Global biodiversity is under threat with extinction rates increasing roughly three orders of magnitude in the last 100 years (Millennium Ecosystem Assessment, 2005) and New Zealand is no exception to this trend. Considered a biodiversity hotspot due to its high endemicity, New Zealand's biodiversity crisis has been primarily fuelled by hunting, destruction of habitat, and introductions of exotic plants and animals that prey on and compete with the native biota (Ministry for the Environment, 2015).

To combat the current threat of extinctions within the animal kingdom a variety of approaches are being put into practice in these hotspots including the eradication or control of introduced pests via poisoning and trapping (Eason et al., 2017). These control operations are either being carried out where the threatened species currently reside, or in another location that has been turned into a 'safe haven'. The animals under threat are then translocated into these predator free/controlled areas where it is hoped that they can thrive (Seddon et al., 2014).

Zoos, originally set up for entertainment purposes, have also become places that not only promote awareness of species, but take an active role in their preservation (Seddon et. al. 2007; Jakob-Hoff et al., 2015). Other efforts towards preserving biodiversity include setting aside large tracts of land such as islands or 'mainland islands' for the specific purpose of conservation for single or multiple species or sometimes entire ecosystems (Craig et al., 2000; Saunders and Norton, 2001).

It is in these hotspots that the intensive use of some of the conservation techniques mentioned earlier are being used to ensure threatened species survival (Myers et al., 2000). The eradication of known threats such as the removal of rats from Santa Cruz Island, the exclusion of pigs from areas in Hawaii, and the multi-predator elimination from numerous offshore and mainland islands around New Zealand have incorporated a variety of techniques such as trapping, poisoning and fencing to obtain a pest-free status and achieve positive outcomes for native and translocated species (Craig et al., 2000; Saunders & Norton, 2001; Miskelly & Powlesland, 2013; Robertson et al., 2016).

Amongst these hotspots, New Zealand, in particular, has a strong conservation obligation made necessary by its history of species declines and local extinctions. Of the 473 bird species resident there (including migrants, vagrants, colonisers and naturalisers), 11.8% have gone extinct, 18.4% are threatened to varying degrees, and a further 22.1% are at risk (Robertson et al., 2012). To combat this threat of extinction, New Zealand is employing a range of methods to secure the survival of its endemic species, including the birds that inhabit the country. As well as pest eradication, species translocation has also become a major tool in New Zealand (Miskelly & Powlesland, 2013; Armstrong et al., 2015), often moving species to areas where pests have been eradicated including offshore islands, 'mainland islands', and fenced sanctuaries.

1.1.1 Offshore islands

For over 40 years wars have been waged against mammalian pests on offshore islands starting with the eradication of *Rattus norvegicus* on Maria Island in 1960 (Towns & Broome, 2003). Islands from 1ha to 11,300ha in size have been made free of mammalian

predators and on many of these islands the flora and fauna are flourishing (Jones et al., 2016). Although island eradications initially targeted *Rattus* spp., eradication programmes are now taking a multi-pest species approach (Towns & Broome, 2003). Since being rid of mammalian predators, many islands such as Hauturu/Little Barrier and Tiritiri Matangi have become strongholds for a number of New Zealand endemic species. Islands are serving as reservoirs so that as the populations of various species increase, individuals can be exported to populate areas elsewhere. Although security lies in an island being surrounded by water, care must be taken that an island is not re-invaded. A safe distance from predator occupied islands or the mainland must be ensured. Visiting boats or people also pose potential threats as they may be unknowingly harbouring fugitive pests (Towns & Broome, 2003).

1.1.2 Mainland islands

In 1995, the Department of Conservation began their 'Mainland Island' programme (Saunders & Norton 2001; Gillies et al., 2003). Up until this point, the saving of species was largely carried out on offshore islands, but the Department's goal was to achieve ecosystem restoration on the mainland via intensive pest management (Saunders & Norton 2001). Six mainland island sites, ranging from 117ha to 6000ha in size, were established and considerable effort at '...rehabilitating habitats, [and] enhancing particular plant and animal populations...' has been attempted. Since the health of the 'islands' is dependent on networks of traps and poison, reduction of targeted pest species should allow for an increase in native species. However, mainland islands are under constant threat of re-invasion (Saunders & Norton, 2001) and despite intensive trapping efforts, mainland islands have sustained losses. Between 2000 and 2009, 29% of Boundary Stream's 83 kiwi were killed by stoats, ferrets and dogs (http://www.sanctuariesnz.org/meetings/documents/Fastier2009.pdf; accessed 15/02/2011). Also, in 2003-04, 13 of 17 transmittered kiwi were killed by dogs in the Te

Urewera mainland island (Department of Conservation, 2006). While predation within mainland island interiors can still occur, it should not diminish the importance of the successes that have been possible.

1.1.3 Fenced sanctuaries

Pest proof fencing was developed to alleviate the constant pressures of reinvasion of areas on the mainland that have received pest eradication (Day & MacGibbon, 2007). This special fencing also attempts to reduce the need for continual poison usage. A number of fence types have been designed and installed including at Lake Waikaremoana in the Te Ureweras and Karori Wildlife Sanctuary in Wellington (Burns et al., 2012). The Xcluder$^{®}$ Pest Proof Fencing company has constructed a number of mammalian-proof fences around New Zealand including at Maungatautari Ecological Island (Waikato), Shakespeare Regional Park (Auckland), Rotokare (Taranaki), and Bushy Park (Wanganui) (Xcluder, 2017). In most cases, pest proof fences have been designed to exclude everything from mice to deer. Despite the easement on predation pressure, pest proof fences, like offshore islands, are still at risk. Trees falling on the fence can compromise its integrity and subsequent reinvasion by patrolling pests can put the enclosed area at risk (Connelly et al., 2009). Quick response to incursions and continued monitoring of potentially affected areas improve the effectiveness of pest proof fences. From 1999 to 2009, fences surrounding 28 areas, ranging from 0.3ha for a skink sanctuary to 3300ha for a multi-species conservation project, were constructed. As of 2012 a total of 8368.5ha had been protected and 63 translocations of 40 species carried out within these areas (Burns et al., 2012). The study described in this thesis was carried out in the largest of these fenced sanctuaries, Maungatautari (Smuts-Kennedy & Parker, 2013).

1.2 Understanding behaviour for conservation species management

"Behaviour: A: The manner of conducting oneself. B. Anything that an organism does involving action and response to stimulation. C: the response of an individual, group, or species to its environment (Merriam-Webster, 2017)".

Recording anything an animal does is to study their behaviour. The connection between animal behaviour and conservation biology is well established and understanding species behaviour is helping to halt the decline of biodiversity (Berger-Tal et al., 2011). Small population extinction, species isolation, dispersal in fragmented populations, predation reduction, minimum area and habitat requirements, captive breeding, population census, and reproductive behaviour are just some of the issues that can benefit from increased knowledge of the behaviour of the target species (Sutherland, 1998). The importance of incorporating insights from behavioural ecology to conservation management has been highlighted by several authors for various species (e.g., Brakes & Dall, 2016; Richardson et al., 2016; Butler & Merton, 1992). Without knowing the behaviours of a species the chances of a successful translocation decrease.

The relatively small areas for animals that zoos provide for visitor viewing have been known to have an effect on the behaviour of the animal enclosed (Seddon et al., 2007). Pacing of the enclosure's edge is a behaviour that is often described (Mallapur & Chellam, 2002) with reference to zoos, and larger habitats are desirable to avoid such stereotypic behaviour. When specifically creating an area for a population, regardless of the number of individuals, the question should be asked, "How big should the area be?" If only a certain size area is available then the question needs to be asked, "How many individuals can the area sustain (Basse & McLennan, 2003)?" Habitat quality, which includes the attributes of food

abundance and distribution, and shelter availability are just some of the factors to consider. Another factor may be at what size area will the species' behaviour be most natural? Determining actual behaviour versus modified behaviour can be difficult especially when the species is cryptic.

1.3 Kiwi

In this thesis, I investigated aspects of the behaviour of a translocated population of the North Island brown kiwi (*Apteryx mantelli*) at the Maungatautari Ecological Island to contribute to its conservation management there, and future management of other potentially upcoming ecological reserves.

1.3.1 Morphological characteristics

Kiwi belong to the biologically distinctive family Apterygidae which are most closely related to emus (*Dromaius novaehollandiae*) and cassowaries (*Casuarius* spp.) (Cooper et al., 1992). Apterygidae owe many of their unusual morphological attributes to living in island isolation for over 65 million years (Cooper et al., 2001). Kiwi are an interesting taxon for study because, besides being flightless, they have paired functional ovaries (Kinsky, 1971), slow reproduction, growth (Bourdin et al., 2009; McLennan et al., 2004) and metabolic rates (Calder & Dawson, 1978), lower body temperatures than most birds (Clark & McKenzie, 1982), they burrow underground, have a well-developed sense of smell (Wenzel, 1968), and all this is combined with the kiwi's evolutionary exploitation of what is predominately a forest niche. Another remarkable kiwi attribute, occurring primarily with brown and little spotted kiwi, is their tendency toward monogamy or serial monogamy (Colbourne & Kleinpaste, 1983; Potter, 1989; McLennan, 1988; Taborsky & Taborsky, 1999; Ziesemann et al., 2011), with little or no evidence of extra-pair copulation, and it is mostly the male that

incubates the eggs (Colbourne, 2002). Another reproductive rarity of kiwi is that the female lays one of the most nutrient-rich eggs ever recorded (Calder et al., 1978). This egg is one of the largest eggs in proportion to her body weight of any other bird; 400% above the allometrically expected value (Sales, 2005; Prinzinger & Dietz, 2001). The outcome of this 'rich', large egg is that after a relatively long incubation period (approximately 80 days), successful hatching yields a fully formed and adult-like feathered, self-reliant, chick (Reid, 1972; Reid & Williams, 1975). This combination of attributes makes for an intriguing and unusual bird.

 The isolation that led to a kiwi's unique biology can be attributed to New Zealand's separation from Australia approximately 75Ma ago (Trewick & Gibb, 2010). The kiwi's evolution as a ground dwelling species is the result of New Zealand's history, which lacked mammalian predators. It is also New Zealand's history of predominately aerial predators that suggests why kiwi adopted a nocturnal lifestyle (Gibbs, 2006). Other evolutionary adaptations include weak-barbed plumage that lacks aftershafts (Reid & Williams, 1975). The feathers appear downy near to the skin's surface and bristly at the tips (pers. obs.). The kiwi's vestigial wings are inconspicuous under its plumage and it lacks an external tail (Reid & Williams, 1975; Robertson et al., 2011). The combination of morphological characteristics, which also includes the presence of facial bristles (Reid & Williams, 1975; Cunningham et al., 2011), created many sceptics when the kiwi was first described to the world (Reid & Williams, 1975).

Other unique characteristics of kiwi are that they are the only extant birds with nostrils positioned at the end of their bill. The structure of the bill, the placement of the nostrils and a well-developed olfactory region of the brain, indicate a developed sense of smell (Bang,

1971; Reid & Williams, 1975). The original assumption was that kiwi relied solely on their sense of smell to find soil invertebrates, but studies to prove this showed mixed results (Wenzel, 1968; Cunningham et al., 2009). Evidence suggests alternative ways of detecting prey: pressure-sensitive mechanoreceptors concentrated at the bill tip locate soil invertebrates through vibrations; a technique also used by waders and shorebirds (Cunningham et al., 2007). Whatever the prey detection method, the unique bill morphology is an indication that kiwi are specialised feeders.

1.3.2 Taxonomy

Kiwi belong to the genus *Apteryx*. Species within this genus have undergone a number of taxonomic revisions in recent years (Weir et al., 2016). Currently five species are recognised (Table 1.1).

Table 1.1- Taxonomy of the genus *Apteryx* in New Zealand including currently accepted species, range, and threat status (Robertson et al., 2017 and other necessary references from Hitchmough et al., 2007; Robertson et al., 2011; Sales, 2005).

Species	Range	Threat status
North Island brown kiwi (*Apteryx mantelli*)	Throughout the North Island	At risk
Great spotted kiwi/raroa (*Apteryx haastii*)	Top part of the South Island	Nationally vulnerable
Little spotted kiwi (*Apteryx owenii*)	On offshore islands such as Kapiti, Tiritiri Matangi, and Motuihe. Also at Karori Wildlife Sanctuary, Wellington & Shakespear Regional Park.	Recovering
Tokoeka (*Apteryx australis*)	Fiordland, Haast Ranges, Stewart and Kapiti Islands.	Nationally endangered
Rowi (*Apteryx rowi*)	At Okarito, west coast of the South Island	Nationally vulnerable

1.3.3 Range of behaviours exhibited

Kiwi have been observed performing a number of behaviours including feeding/probing/foraging (Wenzel, 1968; Colbourne & Kleinpaste, 1983; Taborsky & Taborsky, 1995; Cunningham et al., 2009; Cunningham & Castro, 2011), calling (Colbourne & Kleinpaste, 1983; Miller & Pierce, 1995; Taborsky & Taborsky, 1995; Pierce & Westbrook, 2003; Corfield, 2008), nesting/incubating (McLennan, 1987; McLennan, 1988; Taborsky & Taborsky, 1995; Miles, 1997), engaging in courtship, vigilance, walking

(Cunningham & Castro, 2011), roosting (Taborsky & Taborsky, 1995), excavating burrows (Colbourne & Kleinpaste, 1983; McLennan et al., 1987), defence (McLennan, 1987; McLennan, 1988; Taborsky & Taborsky, 1999), fleeing (Colbourne & Kleinpaste, 1983; McLennan et al., 1987), moulting/preening (Colbourne & Kleinpaste, 1983; Cunningham & Castro, 2011) and establishing territories (Colbourne & Kleinpaste, 1983; Taborsky & Taborsky, 1995; Taborsky & Taborsky, 1999). Obtaining a clear picture of a kiwi's routine is difficult due to the challenges of observing a cryptic bird in forested areas at night time. However, better understanding of kiwi behaviour should lead to better management practices, and therefore more information should be obtained.

1.3.4 Territory & shelter characteristics

Upon reaching sexual maturity kiwi begin to develop territories that they defend with calling and aggression (Taborsky & Taborsky, 1992). McLennan et al. (1987) speculated that the size of a brown kiwi's territory, or the percentage of overlap between territories, may be dependent on the density of the population and/or the quality of the habitat. Topography and/or habitat quality could limit a kiwi's ability to disperse, thereby concentrating the population and restricting the range of an individual or mating pair. Pair bond maintenance could also limit territory size as unmated male kiwi have larger territories than mated males (Taborsky & Taborsky, 1992).

Kiwi may range beyond their territories (Chapter 6).Variation in population density of brown kiwi indicates a range of territory sizes for both pairs and individual birds. At Waitangi State Forest, in Northland, where kiwi populations are known to be relatively dense (McLennan et al., 1987), territories ranged between 5-6ha per mating pair (Colbourne & Kleinpaste, 1983; Taborsky & Taborsky, 1991). At Paerata Wildlife Management Reserve and in the Hawke's

Bay where populations are less dense, home ranges were estimated at 30ha per individual bird (Potter, 1989; McLennan et al., 1987). A population at Tongariro studied by Miles et al. (1997) estimated range sizes similar to that of a less dense population with between 28ha and 92ha per bird. Ponui Island holds the distinction of being one of the densest populations measured; 100 birds per km^2 (Cunningham et al., 2007). There, breeding individuals have home ranges of between 3-5ha and most birds overlap their territories with at least one other bird (Ziesemann, 2011). This high density is consistent with limited dispersal in an island setting. At Tongariro, kiwi have access to huge tracks of land and uninhibited dispersal would allow for greater ranging possibilities. Northland and Waikaremoana populations may very well be hindered by vegetation cover and/or pest status.

Within a kiwi's home range, feeding and sheltering are most likely the priority activities undertaken. With regards to shelter, kiwi can rest in a wide variety of refuges. Northland kiwi showed a preference for sheltering under surface vegetation. In Colbourne & Kleinpaste (1983), 95% of the study birds chose surface vegetation for their daytime shelters. In Paerata, surface vegetation was still the most used shelter type, but at a lower rate; 45.6% (Potter, 1989). Further south in Tongariro, surface vegetation seemed to be used less in proportion to its availability. Although exact percentages cannot be referenced, downed trees and under surface roots were the favoured shelter types (Miles et al., 1997).

At Lake Waikaremoana, McLennan et al. (1987) had two study sites with similar kiwi shelter preference results. At both locations, excavated burrows were the most used shelter types, i.e. 36% and 40%. Natural cavities found favour with 28% and 31% of birds, and 27% and 29% utilised surface vegetation. Hollow logs were used the least with only 9% used at one of the study sites.

Kiwi do not necessarily utilise shelter types in proportion to their availability (Miles, 1997) nor does there seem to be a species preference for a specific refuge type. Shelter preferences may be affected by the seasons, but their usage could also be influenced by their availability and quality. Another possibility is that shelter selection is completely random and kiwi 'duck into' the nearest shelter at the end of the night with minimal discrimination based on quality.

1.3.5 Feeding

Until recently, kiwi were thought to locate their invertebrate prey solely by way of smell. A well-developed olfactory region combined with external nares located at the bill tip seemed to support this hypothesis (Bang, 1971; Reid et al., 1982; Colbourne & Kleinpaste, 1983; Sales, 1995). However, there is now an alternate view of kiwi prey detection. The existence of a kiwi bill-tip organ similar to that of shorebirds, containing a concentrated presence of Herbst corpuscles at the kiwi bill's tip (Cunningham et al., 2007) allows for the detection of invertebrates by vibrations (Cunningham et al., 2009). Subsequent studies showed that kiwi are able to use both olfaction and remote touch in combination or independently to locate their prey (Cunningham et al., 2009).

Kiwi have the ability to consume a wide range of foods. Gizzard and faecal studies have shown annelids (earthworms), coleoptera (beetles), aquatic invertebrates, vegetable matter, and berries make up the kiwi's diet (Reid et al., 1982). This ability to feed broadly could indicate that kiwi feed randomly and that consumption is the result of availability rather than preference (Reid et al., 1982). Colbourne et al. (1990) found little spotted kiwi (*Apteryx owenii*) to be selective feeders of slow moving invertebrates greater than 8mm in size. Scarabaeidae were the most commonly eaten invertebrates (although this study had difficulty quantifying the percentage of earthworms ingested). On Stewart Island, Lepidoptera larvae

(caterpillars) comprised a greater portion of the diet for the tokoeka kiwi (*Apteryx australis*) than in brown kiwi (Colbourne & Powlesland, 1988; Reid et al., 1982). This seemingly preferential diet may be the result of availability.

 Colbourne et al. (1990) found that little spotted kiwi retrieve most of their prey items from the forest soils rather than the forest surface. However, on Ponui Island, Cunningham and Castro (2011) recorded brown kiwi probing the soil in less than half of all probes. The greater proportion of probes occurred in the leaf litter. They also found that female kiwi had 30% longer bills than males and therefore probed deeper in the soil. Gibbs and Clout (2003) speculated about vertical partitioning; that adult kiwi probed deeper than juvenile kiwi because they had longer bills. The greater the bill length, the deeper the kiwi should be able to probe. Therefore adult kiwi, more specifically adult brown kiwi more so than little spotted kiwi or juveniles, and females more so than males, should be able to access deeper soil depths (Colbourne et al., 1990; Gibbs & Clout, 2003). Soil penetration can become difficult during the peak, dry summer months. As a result, alternative feeding strategies are initiated as kiwi are known to migrate from ridge tops and upper slopes to lowland regions and boggy areas (Colbourne & Kleinpaste, 1983). Colbourne and Kleinpaste (1983) speculated that increased soil moisture in these habitat types may facilitate bill penetration and invertebrate extraction and Cunningham et al. (2007) found a positive correlation between probing and soil gravimetric water content.

1.3.6 Reproduction

As previously stated kiwi have slow reproductive rates compared to other birds (Bourdon et al., 2009) with small clutch sizes (up to two eggs in a clutch) and few clutches per year (up to three clutches a year) (Reid, 1981; Cockrem et al., 1992; Potter et al., 1996). The lifting of

eggs for artificial incubation during conservation management often prompts female kiwi to re-lay, allowing for the maximum number of clutches to be produced.

Female brown kiwi lay their eggs in June/July through to February (Cockrem, 1995; McLennan, 1988; Potter, 1989). Although the females have been known to incubate the first few days after laying (Colbourne, 2002), the brown kiwi males are regarded as the solo incubators of any eggs laid (Cockrem, 1995). This contrasts with South Island kiwi species that are known to share incubation duties (Sales, 2005).

A fantastic feat of the female kiwi is that she lays one of the largest eggs in proportion to her size of any other bird (Prinzinger & Dietz, 2001; Cockrem, 1995). The incubation period, which lasts between 70-91 days (Colbourne, 2002; McLennan et al., 2004; Cockrem, 1995; Reid & Williams, 1975) results in precocial chick. After the first egg has been laid there is usually a period of roughly 20 days before another egg may be laid (Colbourne, 2002). Females produce eggs that are incubated by the males, but McLennan et al. (1996) reported that 45% of the eggs in his study were 'duds'. Whether kiwi eggs require a minimum amount of incubation time per 24-hours has not been established. Male infertility and early embryonic death can result in a 'dud' egg, but whether early embryonic death is the result of insufficient incubation time or other causes has yet to be determined.

The male kiwi has been known to breed as early as one to two years of age and females at between two to four years. This is despite not having reached full body size, which occurs at five to six years (Bourden et al., 2009). The average maximum breeding age of captive kiwi is 26 years for females and 28 years for males (Sales, 2005). No data have been published on the breeding ages of wild kiwi.

1.3.7 Predation threats and conservation advances

The only mammalian presence kiwi evolved with were bats. Predatory threats took the form of diurnal flyers. The ability to fly became unnecessary as it was advantageous for kiwi to become ground dwelling and nocturnal to avoid such threats (Gibbs, 2006). As a result, kiwi became flightless. With the arrival of humans and the subsequent introduction of a suite of non-native species to New Zealand, kiwi could not undo millions of years of evolution in sufficient time to adapt to their new-found predators. Dogs and ferrets are the primary killers of adult kiwi while chicks and juveniles are killed more frequently by stoats (Robertson et al., 2011; McLennan et al., 1996). Incidences of kiwi mortality have been repeatedly documented:

- August 2010 - Nine kiwi were killed by stoats in the Wairarapa (Katterns, 2010).

- December 2008 - Up to 70 kiwi were killed by dogs in Northland (ANON, 2008).

- 2008 - Tongariro kiwi team reported a number of losses of kiwi that they attributed to ferrets (Kiwi Hui, 2008).

- 2003-04 - Thirteen of seventeen transmittered kiwi were killed by dogs in Te Ureweras (Department of Conservation, 2006).

- 1990-1995 - One hundred ninety-four kiwi deaths in Northland: 70% of which were caused by dogs (Pierce & Sporle, 1997).

- 1986 - Approximately 500 kiwi were killed in Northland by a single dog (McLennan et. al., 1996; Taborsky, 1988).

With respect to kiwi chicks, stoats are responsible for 60%, and as high as 95%, of deaths per year (Basse & McLennan, 2003; Basse et al., 1999; McLennan et al., 1996). McLennan et al. (2004) documented that at least 29% (and a maximum of 38%) of the birds in their study were killed. They believed that the majority of these were killed by stoats. This study also

found that the predation pressure by stoats drastically decreased once kiwi had reached 800g. From the time of independence, i.e. a few days after hatching when the chick leaves the nest, to when the kiwi reaches 800g, kiwi are most vulnerable to predation by stoats. In Tongariro National Forest, 800-1000g chicks were found to be still susceptible to deadly attacks by stoats and so 1200g was adopted as the 'safe weight' (Colbourne et al., 2005).

With some kiwi species' populations reaching devastatingly low numbers, their restoration has had to become more than just recreating a safe habitat. Intervention with the reproductive process has become necessary to ensure their survival. With less than 5% of kiwi chicks in the wild surviving to adulthood (McLennan et al., 1996), Operation Nest Egg or 'ONE' was developed in 1994 in an attempt to reverse the decline of kiwi populations (Colbourne et al., 2005). ONE dictates that kiwi eggs are lifted from their nests and taken to special facilities to be incubated artificially. Once the eggs have hatched, and the chicks have regained the weight lost after absorbing their yolk sac, they are taken and released into a pest free area. Whether artificially fed or left to find their own food, the chicks reside in their pest free environment until they reach the 'stoat proof' weight of 1200grams. Upon reaching the target weight the (now) juvenile kiwi are then released back into the wild (Colbourne et al., 2005).

1.4 Demystifying knowledge gaps for kiwi conservation

Kiwi live an enigmatic existence. Due to their nocturnal lifestyle, their behaviour often goes unobserved and unrecorded. To date, monitoring studies of kiwi and the assessment of their populations have mostly relied on the remote methodologies of radio telemetry (Taborsky & Taborsky, 1995; Potter, 1990) and calling surveys (Colbourne & Kleinpaste, 1984). An exception is shelter selection studies which cause minimal disturbance to kiwi and the data are easy enough to collect with a radio-tagged population (Jamieson et al., 2016; McLennan

et al., 1987). Wild population kiwi diets are often assessed after the fact by sifting through faecal matter (Colbourne & Kleinpaste, 1983; Colbourne & Powlesland, 1988) and, if a kiwi has been recently found dead, their gizzard contents are itemised (Reid et al., 1982). The results of these investigations have greatly contributed to our knowledge of kiwi and often during these studies observations have been noted about kiwi behaviour (Colbourne & Kleinpaste, 1984). Few studies have attempted to quantify what kiwi do with their time (Cunningham & Castro, 2011), and never has it been done in a fenced enclosure.

The 2008-2018 Kiwi Recovery Plan (Holzapfel et al., 2008) states that to ensure sustainability kiwi managers need, '...to take the health of the ecosystem into account...'. However, we need to first understand how kiwi use ecosystems with respect to feeding and sheltering by individuals, and also individual kiwi interactions with other members of the population by way of territory defence and reproduction. Once known, we can begin to define what a healthy ecosystem looks like for kiwi. By providing an optimal ecosystem, kiwi populations should not only cease to decline but increase to a point where they are no longer threatened.

To improve the conditions of a threatened species, managers must know how a species behaves and what their needs are, especially when space is limited. Activity budgeting is a way to understand the importance animals give to each of a variety of behaviours so managers know what is intrinsic to their survival.

Dunbar's (1992) study on geladas (*Theropithecus gelada*) showed that feeding was the most important behaviour for this monkey as altitude and thermoregulation requirements increased. Consequently, as altitude increased social interactions and group sizes decreased.

In Hanya (2004), a study of Japanese macaques (*Macaca fuscata*), feeding and travelling decreased with temperature, however, he suggested that feeding time increased when supply was low.

When the importance of a behaviour is established, further investigation and management practices can be instigated for the benefit of the species. An example: once managers of the endangered kakapo (*Strigops habroptilus*) realised the link between diet and reproduction, supplementary feeding could be included in kakapo management to facilitate breeding and improve the kakapo's chance of survival as a species (Fidler et al., 2008; Elliot et al., 2001). By understanding the dynamics of different behaviours managers can begin to understand what animals need to thrive. Improving a kiwi's chance of survival took a leap forward when researchers understood the stage at which kiwi were most vulnerable (McLennan et al., 2004). As our understanding of kiwi grows, so too should the ability to increase their species' longevity. A basic question, one that has yet to be adequately answered, is what do kiwi do with their time? Current technologies can establish whether a kiwi is active or stationary, but during the daytime when a kiwi should be sleeping, why are they sometimes registered as moving? What are they doing?

1.5 Study Aims

This study aims to obtain a clearer picture of an adult kiwi's life within fenced areas with a particular focus on activity during the breeding season. To do this, I attempted to:

1. Establish and decipher activity patterns over 24-hours from activity transmitter data.

2. Observe diurnal and nocturnal behaviours of kiwi within the pest free environment of Maungatautari using video cameras.

3. Establish the size and distribution of North Island brown kiwi home ranges within fenced areas

4. Establish the shelter preferences of North Island brown kiwi in fenced areas.

To answer these questions this thesis looks at different aspects of a kiwi's life. After a chapter outlining general methods, each subsequent chapter focuses on aspects of kiwi behaviour. The thesis is therefore organised as such:

Chapter 2 - General Methods

Chapter 3 - Male activity patterns of a fenced population of North Island brown kiwi (*Apteryx mantelli*).

Chapter 4 - Female activity patterns of a fenced population of North Island brown kiwi (*Apteryx mantelli*).

Chapter 5 - Are you sleeping? North Island brown kiwi (*Apteryx mantelli)* sheltering behaviour caught on film.

Chapter 6 - North Island brown kiwi (*Apteryx mantelli*) home range size and distribution within two pest proof enclosures on Maungatautari Ecological Island.

Chapter 7 - Shelter selection of North Island brown kiwi (*Apteryx mantelli)* in a pest proof, old growth forest.

Chapter 8- Conclusions and suggestions for future study of kiwi (*Apteryx* spp*.).*

Chapter 2 - Study Site and General Methods.

2.1 Study site description

Maungatautari is a 3363 ha forested extinct andesitic volcano (Cole, 1978), located in the heart of the Waikato Region, and rising above the surrounding lowlands to a height of 797 m asl (map reference: 38°01′00″S 175°34′00″E). Average annual rainfall is between 1400-1600mm (Smuts-Kennedy & Parker, 2013).

Maungatautari's low altitude forests consist primarily of mature tawa (*Beilschmiedia tawa[1]*), rimu (*Dacrydium cupressinum*), northern rata (*Metrosideros robusta*), pukatea (*Laurelia novae-zelandiae*), rewarewa (*Knightia excelsa*) and mangeao (*Litsea calicaris*) in the over-storey, and hangehange (*Geniostoma ligustrifolium*), pigeonwood (*Hedycarya arborea*), kawakawa (*Piper excelsum*), mahoe (*Melicytus ramiflorus*), pate (*Schefflera digitata*), and kanono (*Coprosma grandifolia*) in the understorey (Burns & Smale, 2002). An array of ferns is common in the groundcover and dense stands of supplejack (*Ripogonum scandens*) can be found throughout.

 It was at Maungatautari that the Waikato community sought to reverse the local decline and extinctions of indigenous biodiversity, including kiwi (*Apteryx mantelli*, henceforth 'kiwi'). They recognised that by providing this biodiversity with a 'safe haven' where no exotic mammalian predators could gain entry, the forest could once again flourish. The Maungatautari Ecological Island Trust (MEIT) was therefore ambitiously formed "To remove, forever, introduced mammalian pests and predators from Maungatautari, and restore

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[1] Scientific names for plants follow the New Zealand Plant Conservation Network (www.nzpcn.org), accessed October 2017.

to the forest a healthy diversity of indigenous plants and animals not seen in our lifetime"
(MEIT Vision, 2001; McQueen et al., 2004).

To achieve this vision, MEIT constructed a 47 km-long pest proof fence (Figs. 2.1, 2.2) and
has attempted to remove all mammalian pests from the 3363 ha within the fence line (Smuts-
Kennedy & Parker, 2013). To date, all pests, except mice, are known to have been eradicated.
Initially, MEIT tested the concepts of fencing around a mountain, eradicating a full suite of
pests in tall bush, and monitoring success, by constructing two enclosures: a 35 ha northern
enclosure (N.E.) (Fig. 2.3) and a 65 ha southern enclosure (S.E.) (Fig 2.4, Speedy et al.,
2007). These enclosures were also surrounded with the Xcluder® pest proof fence (Day &
MacGibbon, 2007) and received two aerial applications of brodifacoum in 2004 in order to
rid the area of non-native animals (Speedy et al., 2007). After intensive monitoring to ensure
all potential predators had been eradicated from the enclosures, reintroductions of locally
extinct native species occurred (Smuts-Kennedy & Parker, 2013). It is within these pest free
enclosures that the North Island brown kiwi were studied for this thesis.

In 2004, kiwi were the first species to be reintroduced to the enclosures. After two and a half
years a total of six kiwi resided in the northern enclosure (average 5.83 ha/bird) and eight
kiwi in the southern enclosure (average 8.13 ha/bird). The draft Kiwi Recovery Plan (2017-
2027) states that a kiwi ceases to be a juvenile when it reaches 1000 grams. According to
McLennan et al. (2004), brown kiwi whose weight has reached 1820 grams are considered
adults. Based on these assessments, Maungatautari's re-introduced brown kiwi were all
classified sub-adult or adult birds. Of the seven males present at the beginning of the study,
only one had been successful at breeding following its translocation. However, it was known
that three males had, or were attempting to nest.

Fig. 2.1- Detail of predator-proof fence along the Maungatautari's Northern Enclosure. Photo by Jillana Robertson
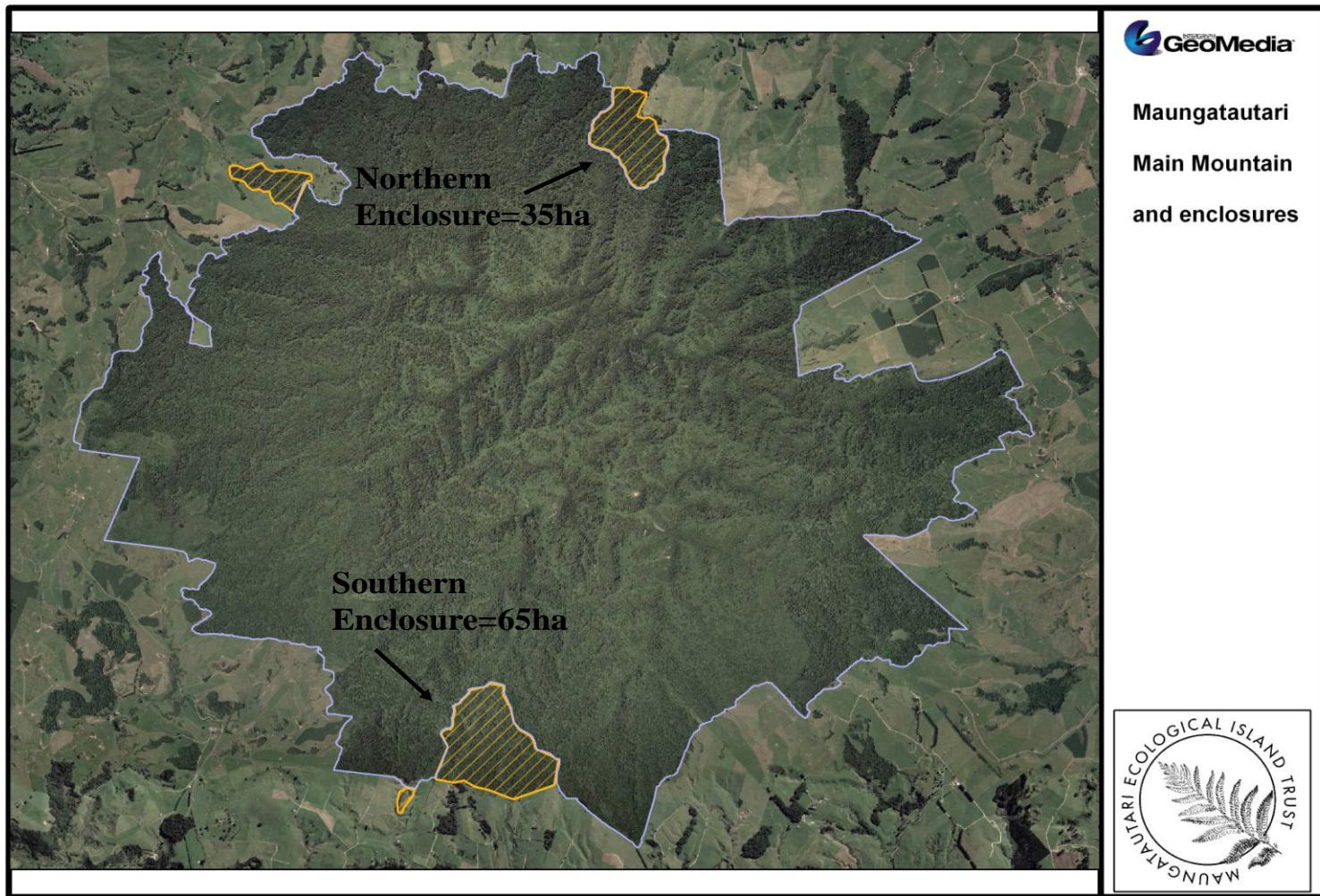
Fig. 2.2- An overhead view of Maungatautari Mainland Island and its enclosures. The blue line around the bush margin signifies the pest proof fence. Yellow striped areas denote enclosures.
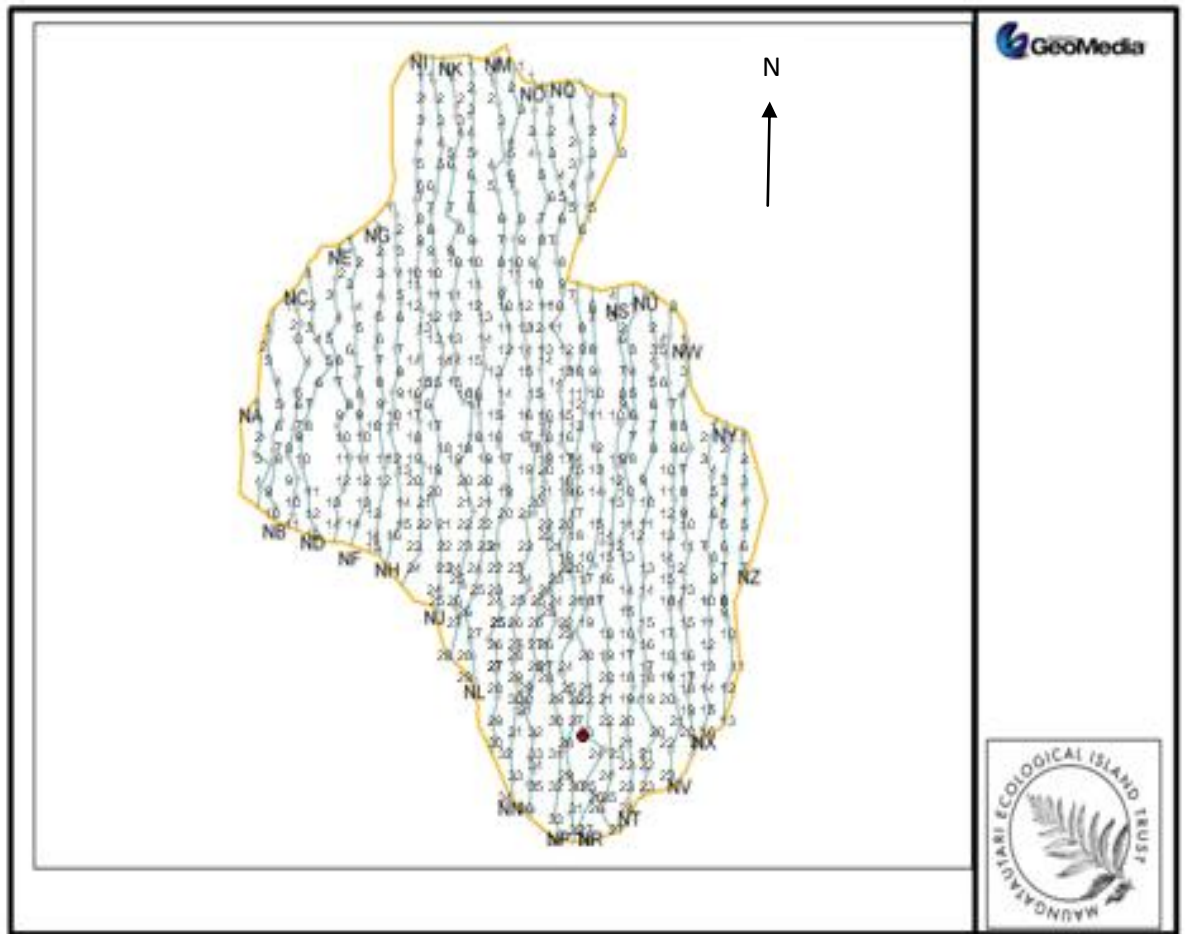
Fig. 2.3- Maungatautari's Northern Enclosure (limits in yellow) with pest monitoring lines set at 25 m x 25 m spacing. Numbers within the enclosure indicate tracking tunnel stations.
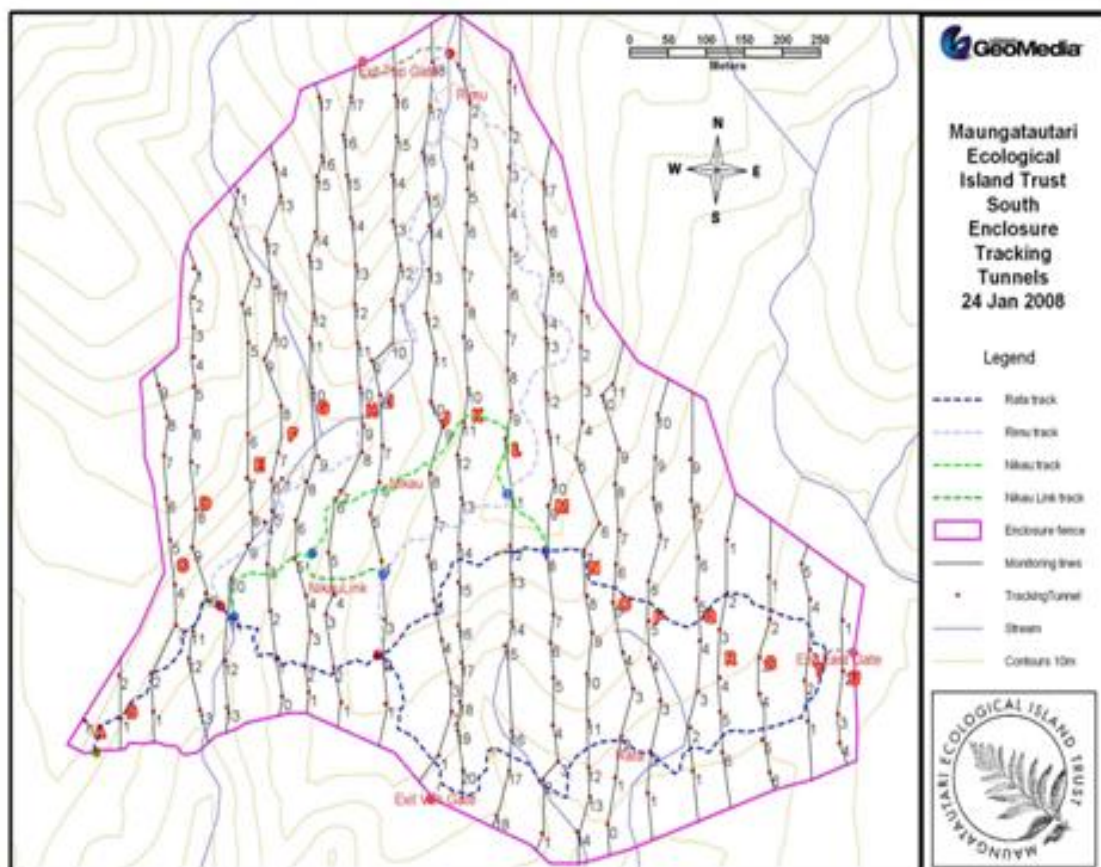
Fig. 2.4- Maungatautari's Southern Enclosure with pest monitoring lines set at 50 m x 50 m spacing. Numbers within the enclosure indicate tracking tunnel stations.

In following years, three species of native fish (*Galaxias fasciatus, Galaxias argenteus, Galaxias postvectis*) (Armstrong, 2017), takahe (*Notornis mantelli*), kaka (*Nestor meridionalis*), yellow-crowned kakariki (*Cyanoramphus auriceps*), hihi (*Notiomystis cincta*), whitehead (*Mohoua albicilla*), tuatara (*Sphenodon punctatus*), North Island robin (*Petroica longipes*), Mahoenui giant weta (*Deinacrida mahoenui*), tieke (*Philesturnus rufusater*), and kokako (*Callaeas wilsoni*) have also been reintroduced (Smuts-Kennedy & Parker, 2013; Parker, 2013; Richardson & Ewen, 2016; Innes, 2017).

2.2. General methods and experimental setup

This section describes some of the general methods that were utilised for different aspects of the fieldwork. Overall, fieldwork on the Maungatautari kiwi population occurred from June 2008 to May 2009.

2.2.1 Radio transmitters

Two different kinds of transmitters were used in this study: '30x60x90' transmitters were used on female kiwi and, at the request of the Maungatautari Sanctuary managers where the kiwi lived, Chick Timer transmitters were used on all males (WildTech Chick Timer User Manual Rowi, V5.2.doc).

The 30x60x90 transmitters emit signals that allow the researcher to know whether or not the bird is currently active, inactive, or dead. A mercury bead imbedded in the transmitter senses motion and this information is detected by a receiver (TR-4) that produces different pulsing rates. A pulse rate of 60 pulses/minute denotes that the transmitter and by default, the kiwi is, at that moment, moving. A pulse rate of 30 pulses/minute indicates that the kiwi hasn't moved in the last 10 seconds, and a pulse rate of 90 pulses/minute signifies that the kiwi hasn't moved in over 24 hours. This could mean that the kiwi is either dead or the transmitter has fallen off.

2.2.2 Male activity

The Rowi "Chick Timer" transmitters (V5.2) had been fitted to all the adult males prior to this study and lasted through the duration of fieldwork. Chick Timer transmitters, in general, are designed to alert managers to the beginning and end of incubation and when the chick has hatched. Although designed for a rowi (*Apteryx rowi*) incubation cycle,

these transmitters were accidently fitted to the Maungatautari North Island brown kiwi (*A. mantelli*), which was fortuitous for this study. The version designed for brown kiwi, which were supposed to be fitted to the birds in this study, gives a series of outputs, two of which indicate the male's total activity for two, 24 hour periods. The rowi transmitter is similarly designed; however, it gives the kiwi's total activity for seven, 24-hour periods, meaning monitoring is needed less frequently; i.e. every seven days as opposed to every two days. All data output from the rowi transmitters are transferrable to brown kiwi (John Wilkes, pers. com.).

In total, twelve outputs are transmitted to a receiver every ten minutes (Wildtech, 2008). These outputs are:

1.   Days since change of state; not incubating = 30 pulses/minute, incubating = 48 pulses/minute, and dead = 80 pulses/minute.

2.   Days since the chick hatched.

3.   Time active yesterday (24 hours).

4.   Time active two days ago (24 hours).

5.   Time active three days ago (24 hours).

6.   Time active four days ago (24 hours).

7.   Time active five days ago (24 hours).

8.   Time active six days ago (24 hours).

9.   Time active seven days ago (24 hours).

10.   Average time active over past seven days (this is a moving average).

11.   Twitch counter (indicates whether the chick is moving around).

12.   Weeks of life remaining on the transmitter.

Note: all activity is recorded in minutes.

To record male activity, the receiver needed only to be within transmitting distance of the kiwi. Pulse outputs were then translated into the male kiwi's activity for the seven days prior plus the moving average over time.

2.2.3 Female activity

See Chapter 4.

2.2.4 Daytime behavioural activity

Footage of kiwi inside their daytime shelters was obtained using a 'burrow camera'. A surveillance video camera fitted with infrared lights was attached to a 20 m extension cable and linked to a recorder in a Pelican 1200 (waterproof) case. The recorder was a MPEG4 Video/Audio Mini Portable Security Recorder which, when coupled with an SD card, could record movement displayed by kiwi. The recorder was powered by a single 12V battery, but cables were spliced to accommodate two batteries that allowed for longer recording time. A 2GB SD card was used inside the recorder, but storage capacity was dependent on image quality, i.e. high quality recording required greater storage capacity than the medium quality setting. A single 2 GB card could capture approximately 5½ hours of continuous footage on the high quality setting as opposed to over 40 hours on the medium quality setting (so long as two, 12V batteries were used). With reference to image quality, the medium quality setting provided images with which I could classify kiwi behaviour with sufficient accuracy, providing there were no obstructions in the foreground to redirect light and focus from the subject.

With the exception of nesting males, the kiwi at Maungatautari were never found consecutively in the same daytime shelters. Therefore, each day a kiwi would be

relocated using radio telemetry, and the burrow camera would be placed in the best position possible. Much care was used when placing the camera so as to disturb the kiwi as little as possible.

 A first attempt to film an incubating male resulted in the abandonment of the nest[2]. This desertion was most likely the result of either the camera being positioned while the male was on the nest, the camera being too conspicuous (shiny silver), and/or because the camera had been placed in the entryway. On subsequent attempts to film incubating males, precautions were taken to avoid further abandonments. These precautions included placing the camera only when the male was off the nest, covering the silver camera casing with black electrical tape, and creating an alternate pathway for the camera. To avoid the camera lying in the kiwi's primary entrance, a second, small access point was dug through which the camera was inserted and placed as flush with the nest wall as possible. All recording gear, i.e. cabling, waterproof recording box and plastic container storing 12V batteries, was hidden at a distance from the nest entrance.

2.2.5 Night time behavioural activity

Attempts were made to follow kiwi during the night and record their behaviour. A Sony DCR-SR42 HandyCam with NightShot™ function was coupled with an infrared spot lamp (IRLamp6, Bat Conservation and Management Inc.) and this combination allowed the kiwi's movements to be documented at night. Kiwi could be filmed up to 20 meters away provided the area was clear of obstructions. Unfortunately, it proved impossible to locate a bird after it had left its daytime shelter and then approach and film it. The noise

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[2] The nest was checked within the next 6 hours and upon realisation of abandonment, the eggs were transferred to Operation Nest Egg in Rotorua. Subsequent candling by Operation Next Egg revealed that the eggs were infertile.

I, as the observer, made when approaching the kiwi was too disruptive. The kiwi would invariably stay out of viewing distance and the rest of the night was spent trying to catch up to it. An alternative tactic was to locate the kiwi prior to nightfall and start filming as soon as it departed from its shelter. This method was usually successful (unless the kiwi exited out a different entrance than the one the camera was trained on); however, the dense vegetation in the Maungatautari enclosures made it difficult to maintain a view of the bird once it had moved only a few metres. This, in conjunction with the difficulty of moving through dense vegetation in the dark made filming while following the kiwi impossible. Fortuitous encounters with kiwi were rare and could not be relied on to gain behavioural data. Therefore, after three months of attempting to film kiwi at night, this part of the project was abandoned.

2.2.6 Other methods

Calling surveys were carried out on both enclosures to ascertain what percentage of the kiwi's time was spent being vocal. Also, daytime shelters were classified and locations recorded to obtain refuge preference and home range sizes. Health checks, which included measuring weight and bill length and visually assessing body condition, were performed on the majority[3] of the kiwi (providing they hadn't dropped their transmitter) at the beginning, middle and end of the eight month study period. All kiwi appeared in good condition during their health checks at the beginning and throughout the study. Other information, concerning kiwi couples was recorded, as was any other observed behaviour.

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[3] Some of the male kiwi had already begun incubating at the start of the study and therefore could not be handled. Their health checks were carried out once incubation had concluded.

Chapter 3 - Male activity patterns of a fenced population of North Island brown kiwi (*Apteryx mantelli*).

3.1 Introduction

"The time animals allocate to various activities has significant consequences for their survival" (Hanya, 2004). Feeding, grooming, vigilance, travelling, resting and social interactions, i.e. mating and communication, are just some of the activities that most, if not all, vertebrates engage in. Day/night length, temperature, altitude and food availability are all known to affect behavioural rhythms (Pepin et al., 2006; Hanya, 2004). Feeding has been ranked the highest in priority amongst vertebrate behaviours and has the greatest effect on the shape of an activity budget (Hanya, 2004; Kurup & Kumar, 1993). Some behaviours, such as mating, can be seasonal, but seasonality can cause other types of fluctuations in activity. For example, ground dwelling insectivores may increase their foraging when rainfall increases soil penetrability. The ability to fluctuate behaviour patterns lets animals adapt to variable environmental conditions. Understanding what determines patterns and prompts activity fluctuations can enable wildlife managers to improve habitat conditions for populations, especially those that are threatened.

The New Zealand kiwi is a threatened bird whose (mostly) nocturnal lifestyle makes its habits unknown. Although a comprehensive 24-hour activity budget is far from complete, some kiwi behaviours have been recorded by cameras aided by infrared spotlights at night. Preening, probing, prey manipulation, walking, and vigilance have all been exhibited by kiwi (Cunningham & Castro, 2011). Direct observation and burrow cameras (e.g., Chapter 5) have also allowed behaviour patterns to be assessed,

but obtaining these data can be complicated by dense understory and multi-tunnel burrows. A kiwi's aversion to human presence complicates data collection (pers.obs.). Remote transmitter technology, although not providing a visual record of detailed behaviour, can give a broad view of kiwi activity without disturbing the subject.

Activity patterns will also vary by gender due to key differences in roles associated with reproduction. As incubation is the role of the male brown kiwi, their behaviour will differ from that of females (Female behaviour is looked at in Chapter 4). It also stands to reason that the behaviour of unpaired males will differ from paired males and that paired male behaviour will vary with season.

 Of the four taxa of North Island brown kiwi, this study looks at male western North Island brown kiwi activity types and levels in and around the breeding season and compares the total activity of incubating versus non-incubating birds. I also investigate how male activity changes with season, night/day length, rainfall and breeding status in a forest reserve absent of predators.

3.2 Methods

For Site description see Chapter 2.

3.2.1 Species description

The western North Island brown kiwi (*Apteryx mantelli*, henceforth 'kiwi') is not only interesting because it is a flightless insectivore, but because the male almost exclusively incubates eggs that are 400% above the allometrically expected size (Prinzinger & Dietz, 2001, Chapter 1). Incubation of a clutch by the male lasts an average of 80 days

with up to two eggs that are laid 20-30 days apart (Burbidge et al., 2003). Depending on the management of the population a kiwi can lay up to three clutches in a breeding season (Colbourne, 2002; Sales, 2005).

3.2.2 Study population

Maungatautari had a total of 15 kiwi divided between the two enclosures during the period I undertook this study. I looked at three adult males in the northern enclosure and four adult males in the southern enclosure. Prior to this study, only one male kiwi had successfully incubated and hatched a chick at Maungatautari (pers. com. C. Smuts-Kennedy).

All male kiwi were fitted with WildTech 'dual incubating' rowi "chick timer" transmitters V5.2 (Wilkes, 2008). These transmitters are designed to alert kiwi managers to the beginning and end of the male's incubation. A mercury ball within the transmitter detects the kiwi's increases and decreases in activity. Each transmitter is tuned to a specific frequency and when a receiver is set to that same frequency a series of outputs is transmitted (See Chapter 2). Activity within the output series was recorded in 24 hour periods and all series outputs for all kiwi were recorded remotely from July 2008 to March 2009 during field work in the enclosures undertaken for other studies (Chapters 4, 5, 6, 7). Because the activity or inactivity was recorded in 24 hour units, there was no differentiation as to whether the activity took place during the night or daytime. Since kiwi are known to be primarily active at night, I assumed that *all* activity transmitted was taking place at night and *all* inactivity was occurring during the day. If the length of activity recorded exceeded night length then I assumed it was carrying over into daylight hours.

Three attempts were made to film incubating males using a nest camera (Data not presented here). Two attempts were successful and one attempt caused abandonment of the nest. Any eggs that were abandoned, naturally or rarely through unintentional researcher disturbance were lifted and taken to Rainbow Springs, an egg and chick-rearing facility (https://www.rainbowsprings.co.nz/kiwi-conservation/ , accessed November 2017). If the eggs were fertile and the embryo still alive, they were artificially incubated and hatched there. It was a rare occurrence, but once the chicks had regained their hatch weight, they were re-introduced into the territory of the male kiwi that had originally incubated them.

3.2.3 Statistical analysis

Data were normally distributed (Shapiro-Wilk Test: incubating birds W= 0.852, *P*=0.129; non-incubating birds W=0.979, *P*= 0.931), therefore parametric tests were used for analyses. Seasonal differences in activity were investigated using the average of kiwi activity over three-month periods. These periods were centred around the solstices and equinoxes and were defined as follows: Winter from 8 May - 6 August; spring 7 August - 6 November; summer 7 November - 4 February; autumn 5 February - 7 May.

T-tests were used to identify significant differences between total time active for incubating and non-incubating males and the proportion of night active (hours active/ night length). Means and standard deviations were also calculated for the total time active and the proportion of the night active of individual birds. One-way ANOVA tests were used to look at the effect of season, as a factor, on total activity and proportional

activity, as dependent variables. Tukey's multiple comparisons test was used to identify seasonal differences.

3.3 Results

3.3.1 Activity

Over the eight-month period that this study took place kiwi activity was recorded anywhere from 140-187 days per bird (Table 3.1). The amount of data collected was variable due to one transmitter failing near the end of the study, another bird being introduced into the enclosure partway through the study, and the inability to locate some birds at times (Table 3.1). Most data were collected in spring and summer, and no breeding occurred in autumn, hence no birds were recorded incubating then. Incubating males spent significantly less time active (mean = 287.3 minutes per day; sd = 44.03) than non-incubating males (mean = 603.4 minutes per day; sd=45.4; t-test, *P <0.001*). Non-incubating males were active on average 95.8% of the night hours (mean= 0.958; sd =0.065) which was significantly longer than incubating males that spent 43.3% active (mean= 0.433; sd= 0.106; t-test, t= 59.39, *P< 0.001*, Table 3.2, Figs. 3.2, 3.3). Male kiwi activity was not restricted to night hours. Six out of seven kiwi males were, at times, active during daytime hours, however, this activity could have taken place in or out of the shelter/nest. This activity during daylight hours was more often recorded during the summer months (Figs. 3.2, 3.3).

Table 3.1 - Number of days sampled for individual birds during and outside of incubation and in each season.

Bird	Breeding Status	Total Days	Winter	Spring	Summer	Autumn
Parure	Incubating	85	16	39	30	---
	Not incubating	99	---	28	48	23
Elmo	Incubating	60	---	28	32	---
	Not incubating	115	8	40	44	23
Robin	Incubating	87	17	45	25	---
	Not incubating	100	---	27	50	23
Tuatahi	Incubating	36	15	21	---	---
	Not incubating	126	---	43	66	17
Mark	Incubating	23	---	---	23	---
	Not incubating	107	---	31	54	22
Puke	Incubating	N/A	---	---	---	---
	Not incubating	140	6	58	66	10
Tari	Incubating	N/A	---	---	---	---
	Not incubating	139	6	52	67	14

Table 3.2- Activity means of individual birds in terms of total minutes active per day and proportion of night active. Stdev= standard deviation. *= kiwi never incubated.

	Robin	Parure	Elmo	Mark	Tuatahi	Puke	Tari	Mean	Stdev
Non-incubating males total activity (minutes per day)	576.8	675.2	611.9	548.6	563.0	602.3	645.8	603.4	45.4
Incubating males total activity (minutes per day)	259.8	346.4	257.5	322.6	250.3	*	*	287.3	44.03
Non-incubating males proportion of night active	0.926	1.075	0.918	0.894	0.923	0.950	1.018	0.958	0.065
Incubating males proportion of night active	0.377	0.511	0.423	0.575	0.309	*	*	0.439	0.106

a. Parure
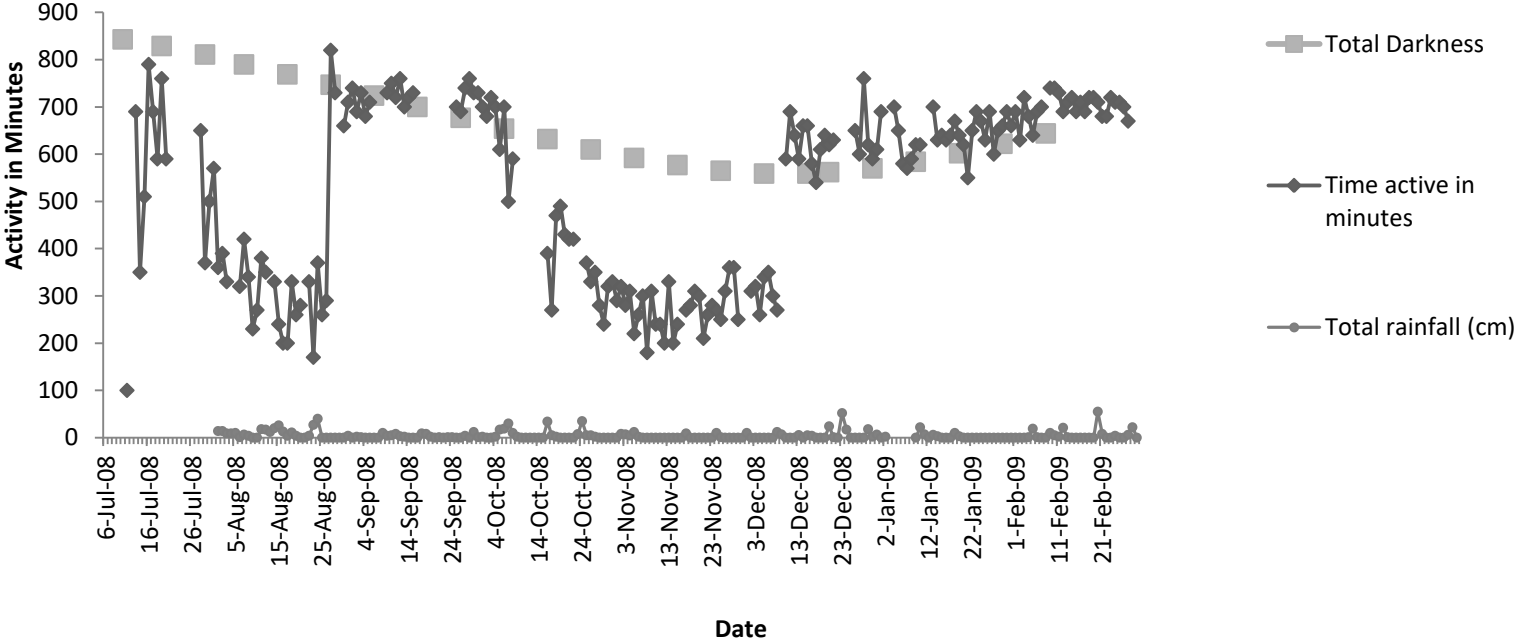
b. Robin
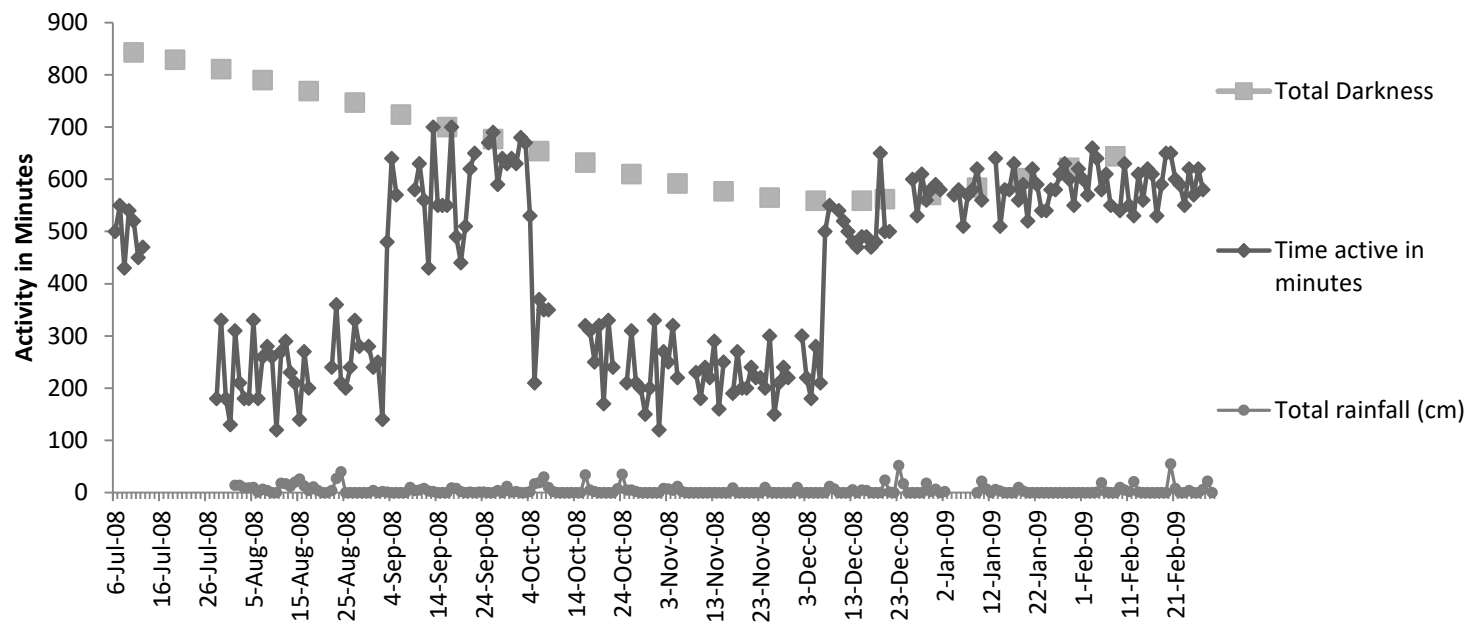
c. Mark
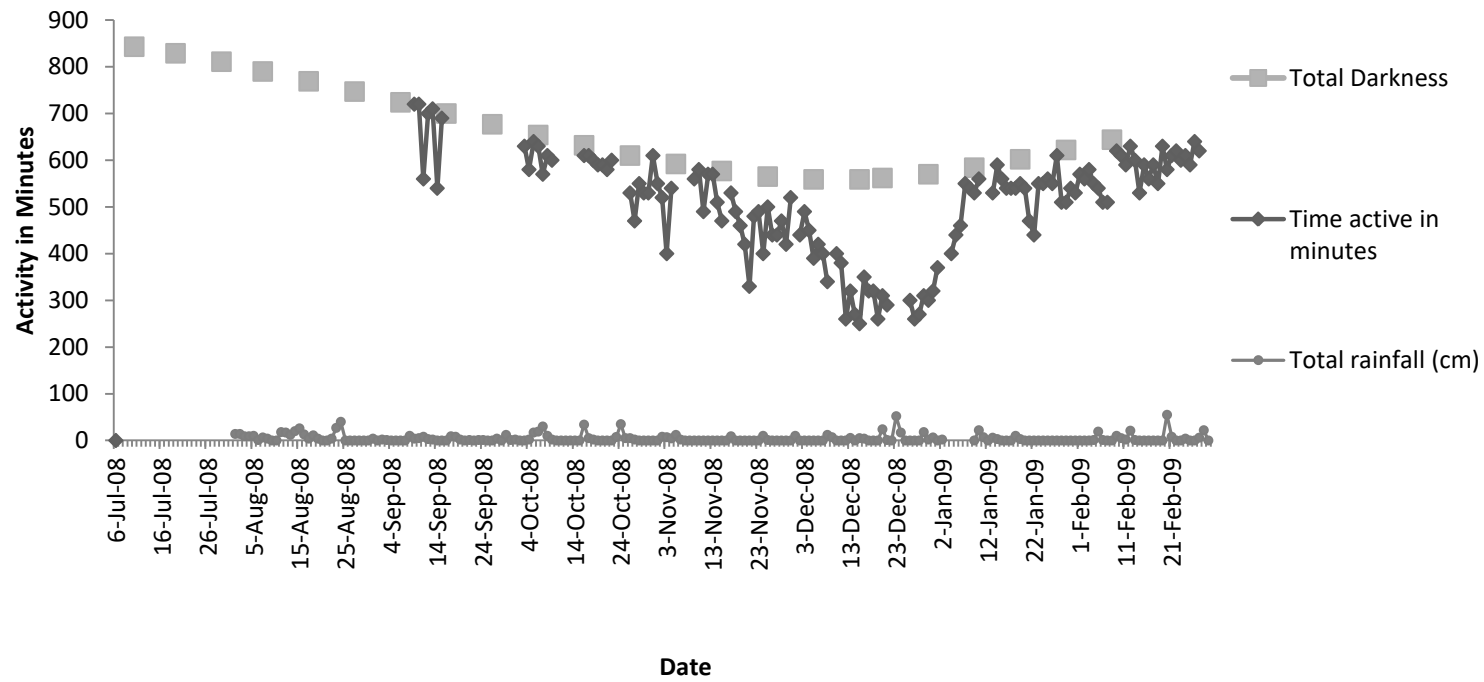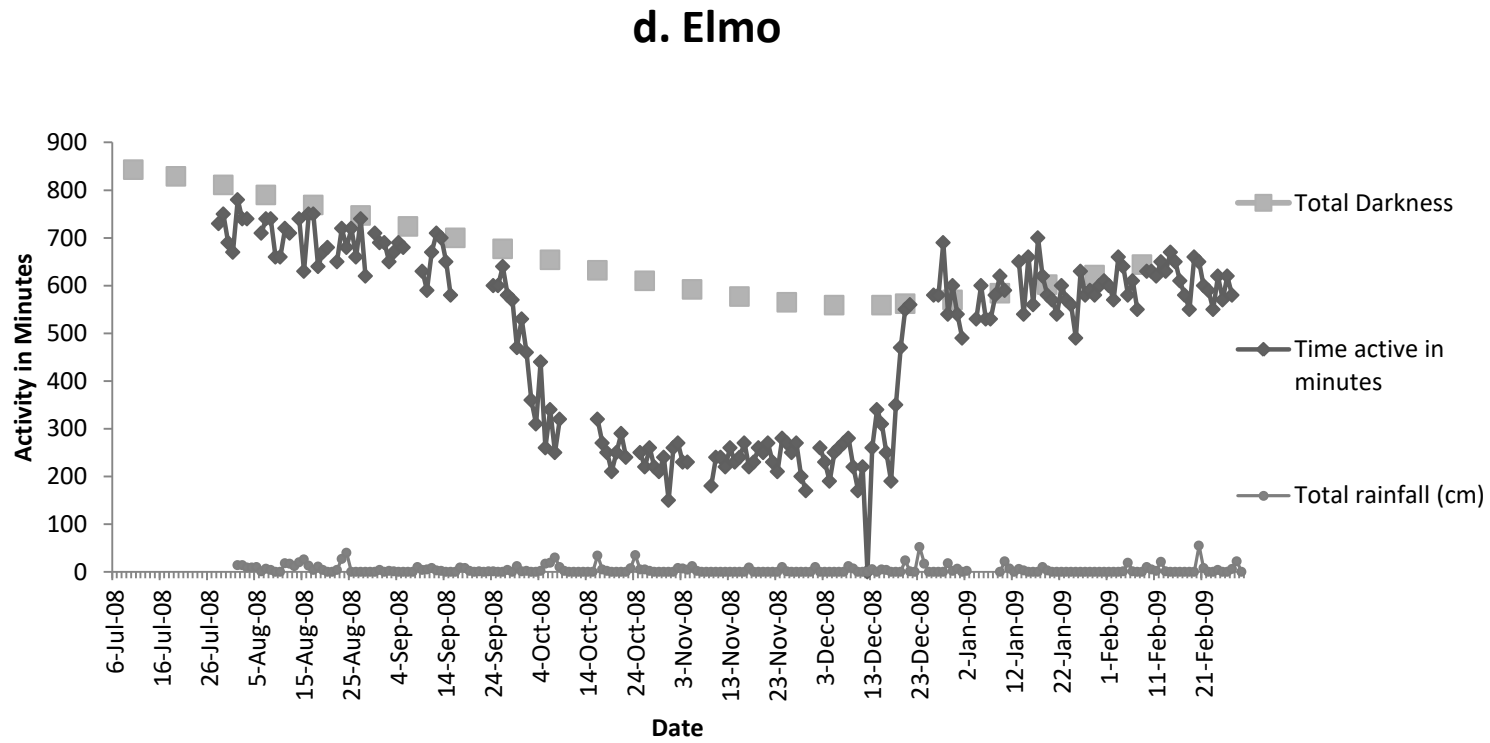
d. Elmo

Figs. 3.2 a-d- Southern Enclosure male kiwi activity, total amount of darkness and average total rainfall; a. Parure, b. Robin, c. Mark, d. Elmo were the male brown kiwi in this enclosure. Periods of lower activity indicate incubation.

a. Tuatahi
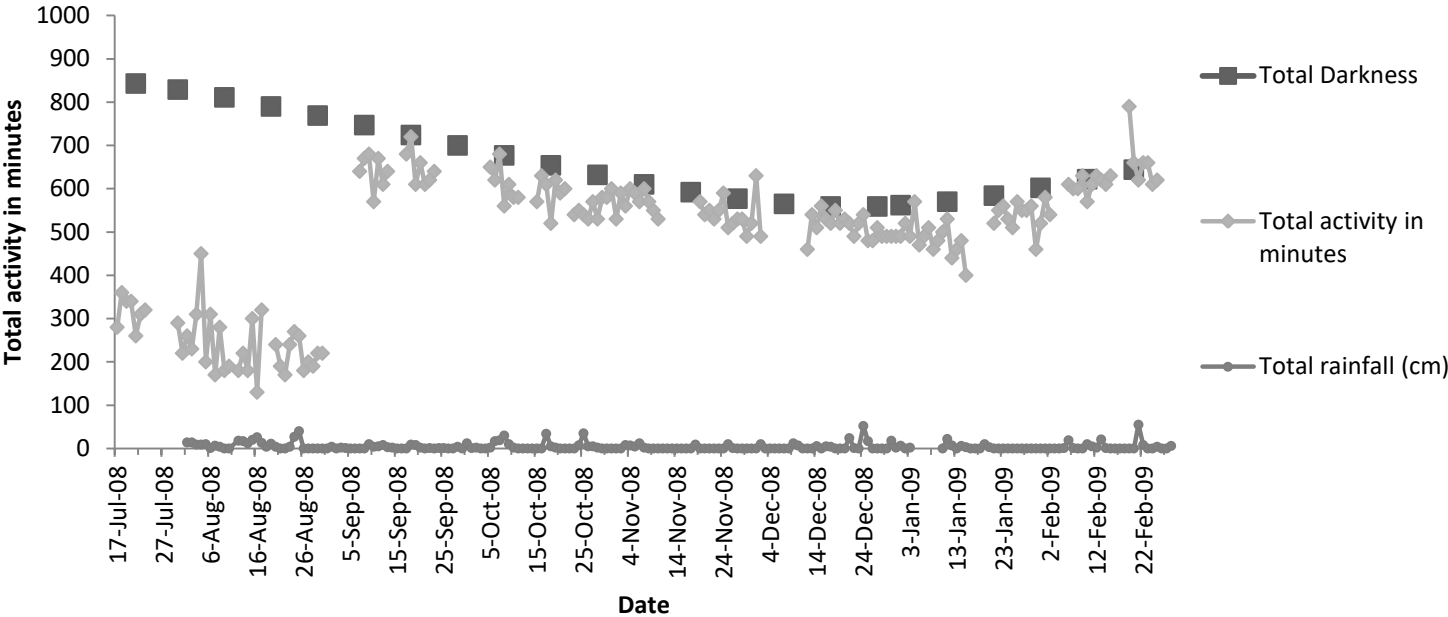
b. Puke
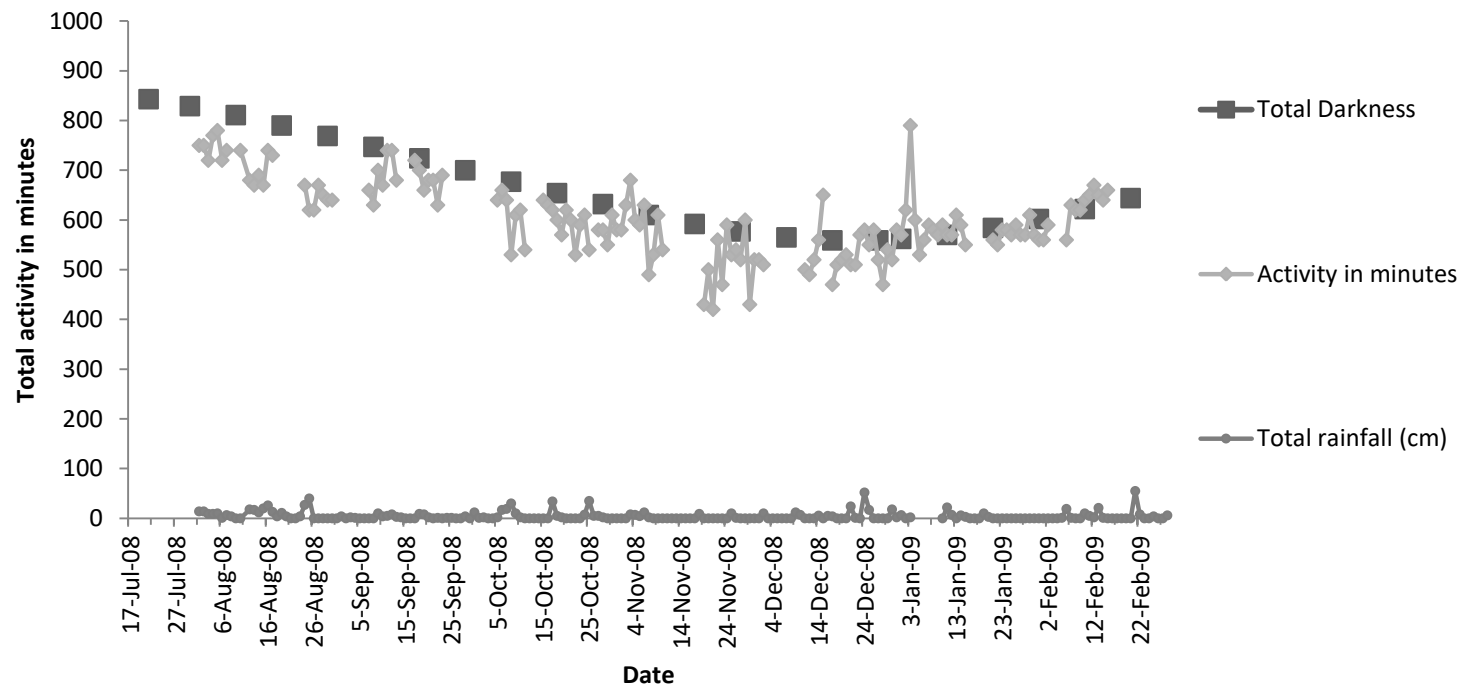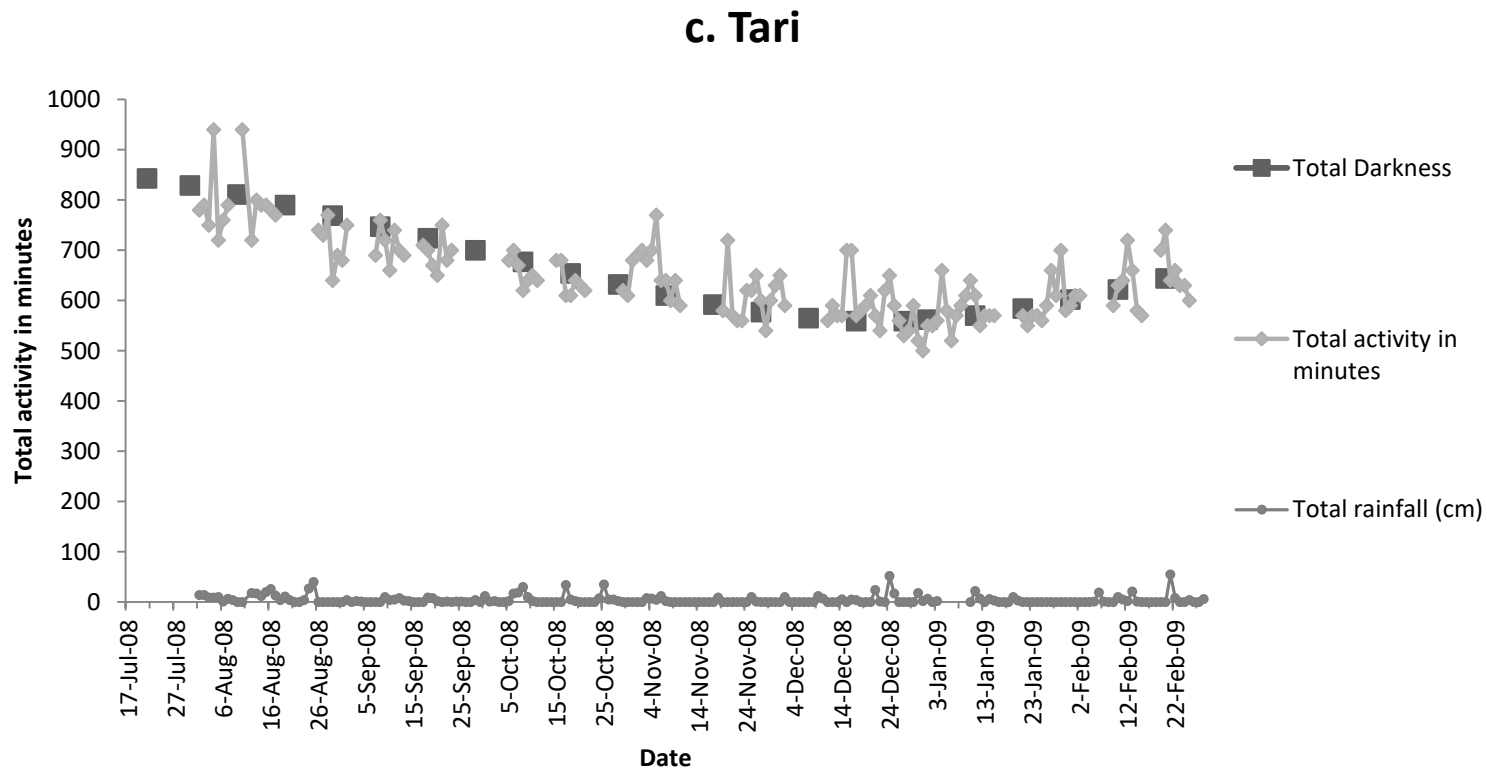
c. Tari

Figs. 3.3 a-c- Northern Enclosure male kiwi activity, total amount of darkness and average total rainfall; a. Tuatahi, b. Puke, c. Tari were the kiwi in this enclosure.

3.3.2 Activity fluctuations during incubation

The only distinguishing trend of incubating males was that they tended to be more active towards the beginning of the incubation period than later (Fig. 3.4a-g). After the first few days of incubation, their activity levels were low with little variation.
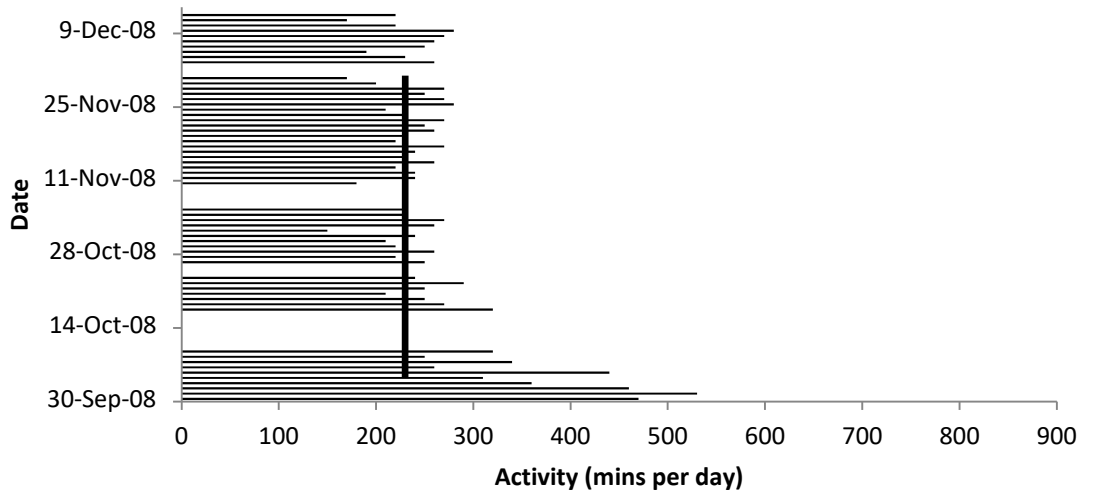
Fig. 3.4a - Activity (mins. per day) of Elmo during a successful wild hatch of one egg. The black line indicates mean activity of incubating bird.
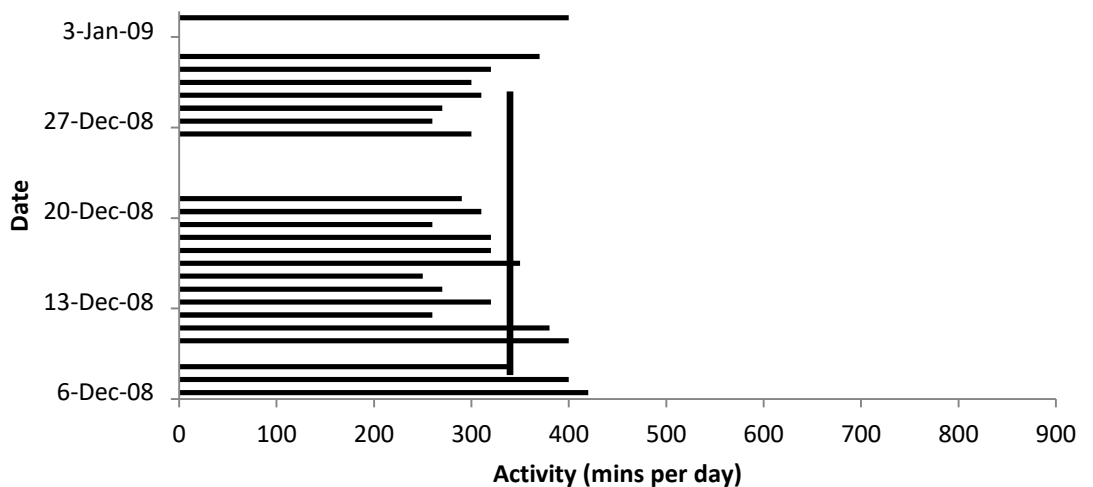
Fig. 3.4b- Activity (mins. per day) of Mark during incubation of a single infertile egg that was abandoned. The black line indicates mean activity of incubating bird.
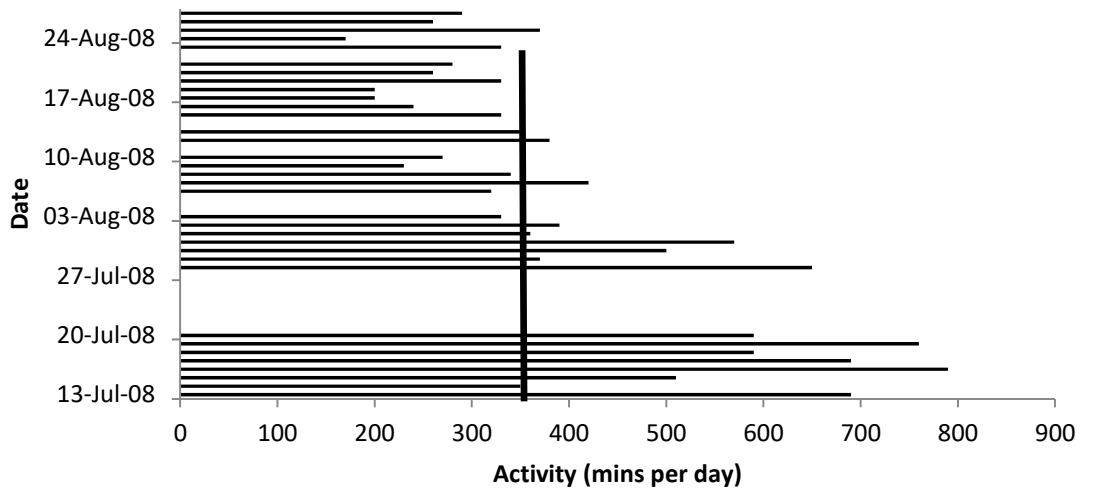
Fig. 3.4c- Activity (mins. per day) of Parure during incubation of two infertile eggs that were abandoned (abandonment most likely due to researcher disturbance). The black line indicates mean activity of incubating bird.
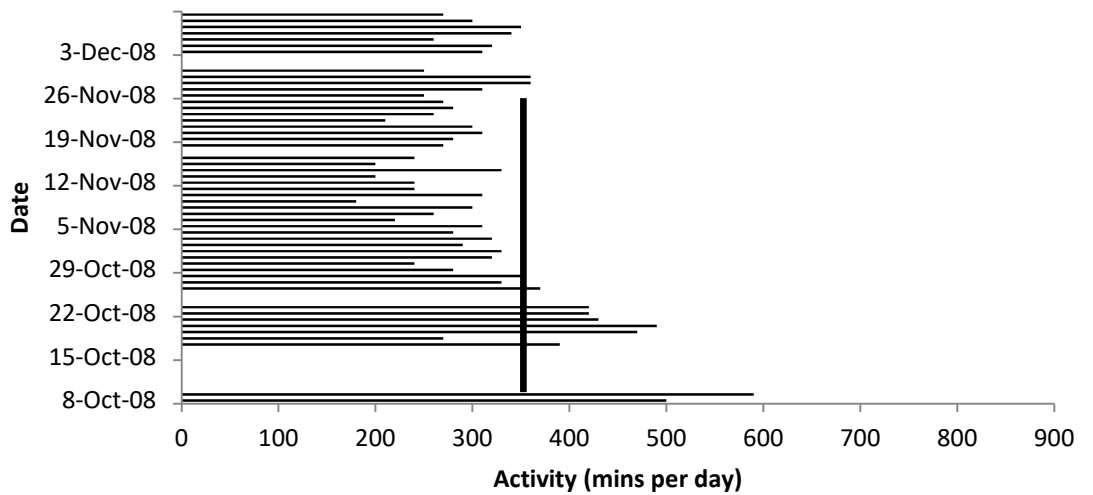
Fig. 3.4d- Activity (mins. per day) of Parure during incubation and clutch lift that resulted in two eggs that had failed due to early embryonic death (One embryo died at 20 days the other at three). The black line indicates mean activity of incubating bird.
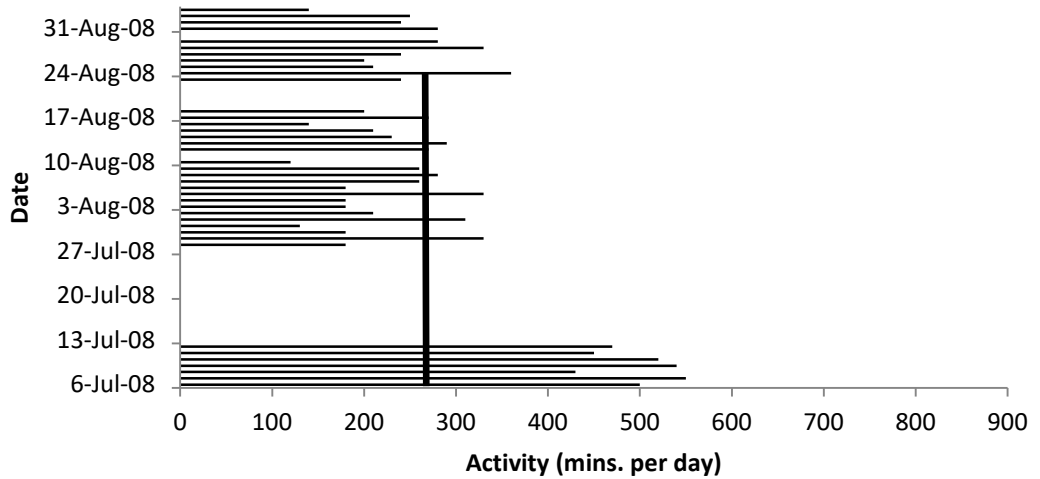
Fig. 3.4e- Activity (mins. per day) of Robin during incubation of two viable eggs that were lifted and artificially hatched. The black line indicates mean activity of incubating bird.
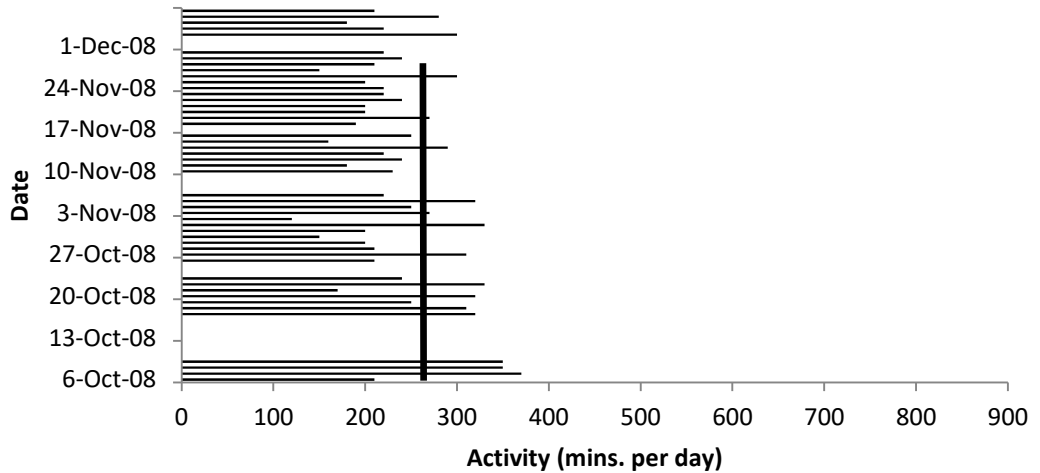
Fig. 3.4f- Activity (mins. per day) of Robin during incubation of two eggs abandoned (most likely due to researcher disturbance); one egg successfully hatched after being removed and artificially incubated, the other had been completely buried in the nest. The black line indicates mean activity of incubating bird.
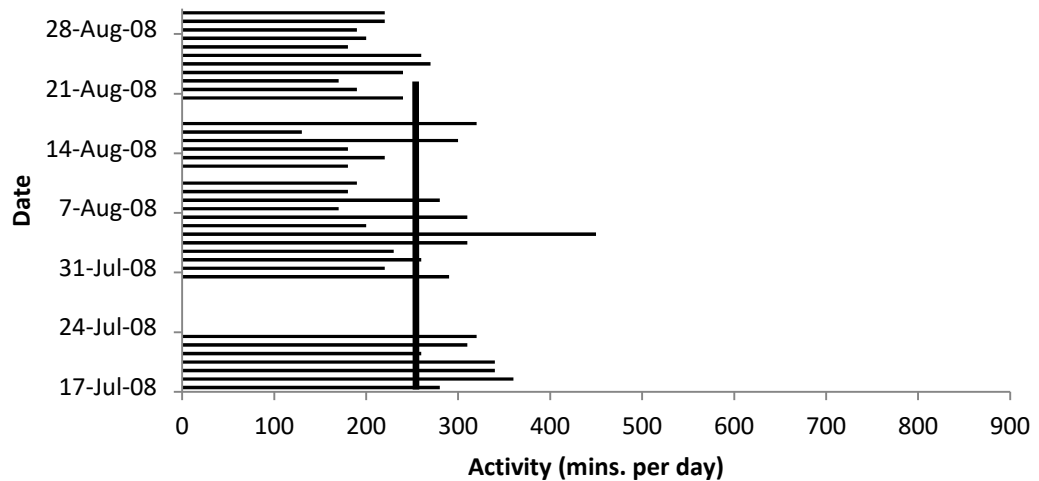
Fig. 3.4g- Activity (mins. per day) of Tuatahi during incubation of a single egg that was retrieved, but was so rotten it was unclear whether it had been infertile or had died. The black line indicates mean activity of incubating bird.

3.3.3 Seasonal activity

When male kiwi were not incubating there was no significant difference in proportion of night active among the seasons (ANOVA, F=1.530; d.f. =3; *P*=0.238, Table 3.3). Assuming the majority of kiwi activity occurred during the night, the average period of kiwi activity in relation to the number of night hours was the same irrespective of the season. However, total activity of non-incubating male kiwi differed significantly between seasons with the exception of autumn and spring. The greatest difference in seasonal activity was between winter and summer with a decrease of nearly 200 minutes (Fig. 3.5). Spring and autumn have similar night and day lengths and therefore I expected that kiwi activity levels for those seasons would be similar. This is the case for total activity, but in autumn the proportional activity was higher (Fig.3.6).

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Table 3.3: Seasonal mean activity (mins. per day) and proportion night active of individual male kiwi when not incubating

Season	Parure	Robin	Elmo	Mark	Tuatahi	Puke	Tari	Mean	Stdev
a. Total activity (mins. per day)									
Winter			726			748	790	754.9	32.4
Spring	716	593	672	591	602	641	699	644.9	51.9
Summer	639	562	541	509	520	551	592	558.9	44.6
Autumn	702	590	610	588	631	634	642	628.3	38.9
b. Proportion night active									
Winter			0.880			0.913	0.963	0.919	0.042
Spring	0.989	0.829	0.879	0.917	0.923	0.934	1.011	0.926	0.062
Summer	1.110	0.977	0.937	0.869	0.904	0.958	1.030	0.969	0.081
Autumn	1.104	0.928	0.960	0.924	0.997	1.017	1.008	0.991	0.062
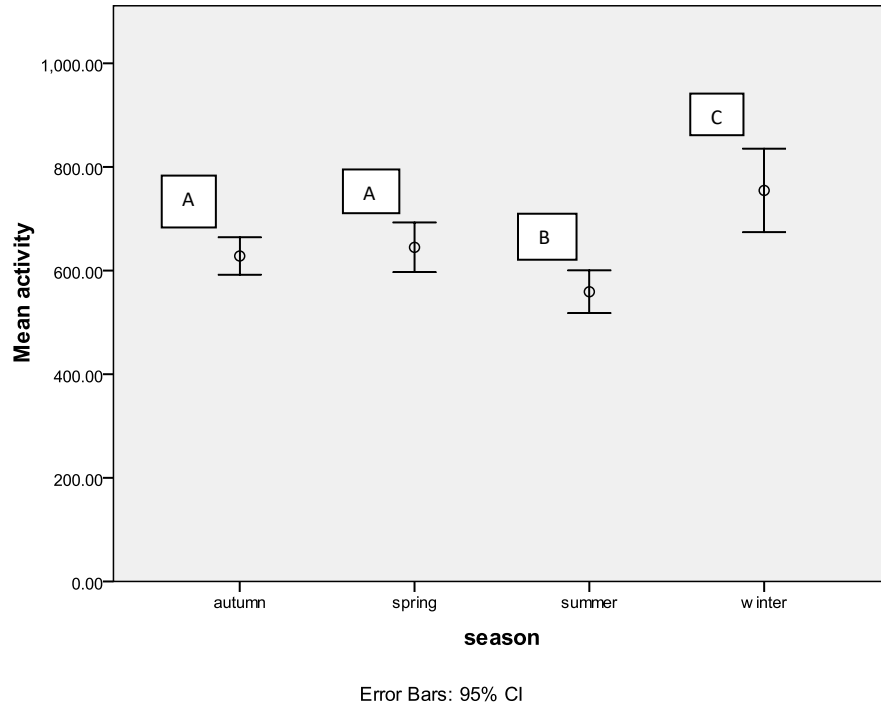
Fig. 3.5- Seasonal total activity (mins. per day) of male, non-incubating kiwi. Points with dissimilar lettering indicate a significant difference among seasons.
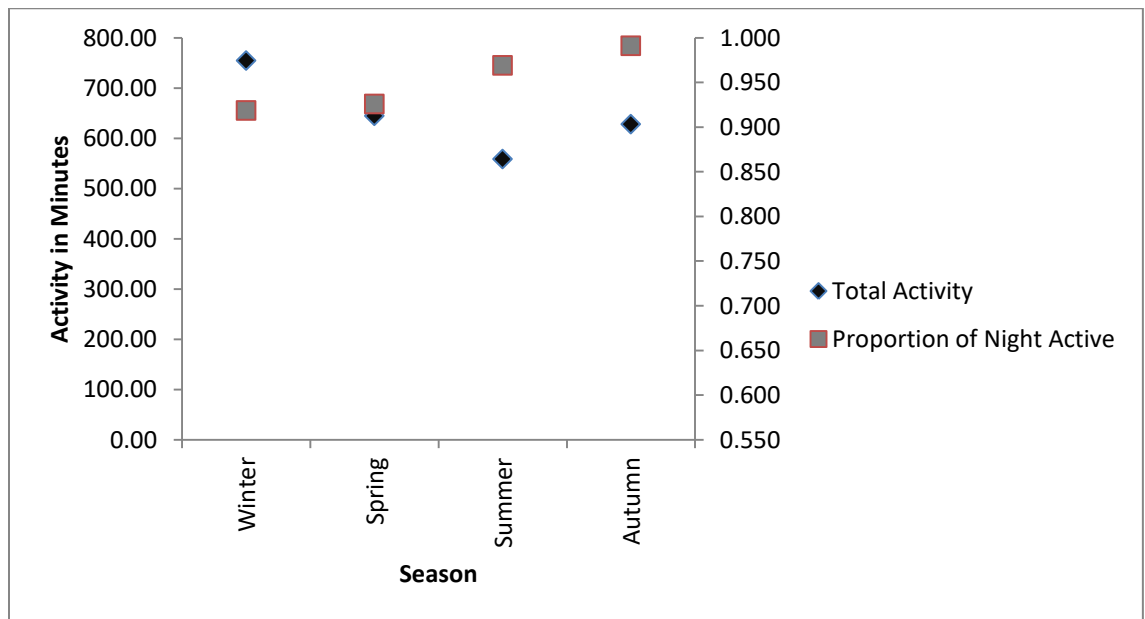
Fig. 3.6- Seasonal relationship between total activity and proportion of night active of non-incubating male kiwi.

3.4 Discussion

My results show that incubating males are much less active than non-incubating males. A sharp increase in activity makes it obvious when males have ceased incubation, but a gradual decrease in activity makes the definitive start of incubation less apparent. Activity dropped to zero for a male in this study the day his egg hatched (Fig. 3.2d). Colbourne (2002) studied the incubation behaviour of NI brown kiwi males and recorded similar behaviour when a male had hatched his chick. Colbourne suggested that the male's constant presence at the nest was because the recently hatched chick was wet and required warmth and insulation. As no other males in this study naturally hatched their chicks, no further comparisons can be made.

3.4.1 Activity fluctuations during incubation

Using direct observation, Colbourne (2002) also recorded that kiwi spent time off their nests for about five hours during the middle stages of incubation. As the hatch date approached, the time spent off the egg decreased to about three hours (Colbourne, 2002). The Maungatautari kiwi did not follow a similar pattern. In my study, during the early stages of incubation, males were recorded being active anywhere from 350-800 minutes. By week three, all the male kiwi had settled in at a lower rate of activity; 120-350 minutes. Throughout the remainder of incubation activity fluctuations occurred every few days, i.e. if a bird had relatively high activity on a particular night, then the following night their activity was relatively low (e.g., Figs. 3.2b & 3.2d). An incubating male has limited time to be active and successfully nurture an egg, with feeding still likely to be a priority behaviour (Hanya, 2004; Kurup & Kumar, 1993). Using this rationale, extra feeding on one night could allow more diligent sitting on the next (or vice versa). It is possible that the increased

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activity is also being used to engage in other behaviours such as maintaining pair bonds or territories. Since the transmitters do not indicate at what point in the 24 hours the activity is taking place, it may be that the increased activity is happening in the nest. Colbourne (2002) wrote that kiwi turn their eggs, so perhaps this recorded activity has to do with repositioning eggs.

Days with higher activity coincided, some of the time, with periods of rainfall although not every time. It could be that kiwi occasionally took advantage of more penetrable soil caused by rain events, but a rain event did not always mean higher activity (Figs. 3.2 & 3.3).

3.4.2 Seasonal activity

Total activity of non-incubating birds tended to decrease with decreasing night length, but its nearly inverse relationship with proportion night active wasn't absolute (Fig. 3.6). As there was no significant difference between autumn and spring total activity, autumn's activity as a proportion of night length was higher than expected. Winter's proportional activity was high as well. This could be because kiwi activity was not recorded throughout all of autumn and winter; only the end of winter and the beginning of autumn were recorded. Another reason for higher than expected proportional activity during autumn could be due to increased foraging efforts. After the dry summer the kiwi may have needed to restore any lost condition. In both scenarios, if activity had been monitored throughout the rest of the season, we may have seen a decrease in the seasonal mean. Similarities between autumn and spring's total activity could be explained by the fact that during spring, kiwi were in and out of incubation. Following incubation it would be expected that a kiwi

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would increase its foraging efforts, and therefore its activity, to regain any weight lost during sitting. Complete weight charts are unavailable for comparison due to regulations regarding policies preventing weight checks on incubating males.

3.4.3 Individual activity patterns

Activity levels varied among individual kiwi and may partly reflect age and experience at incubation. Parure was usually the most active male kiwi in terms of total activity when he was incubating or not incubating and also in his proportional activity when not incubating (Table 3.2). Only Mark was higher (0.575) in his proportional incubating activity than Parure (0.480). This may be attributed to Mark's irregular incubating. Mark was noticed in the same shelter for some time before his transmitter switched to incubating mode. His incubation period lasted just under a month before abandoning what turned out to be an infertile egg. Mark's activity during his supposed non-incubation period was comparatively lower, but his activity during his official incubating period was, on average, higher. High activity when incubating would seem like poor commitment to sitting. Like Mark's unsuccessful attempt at reproduction, Parure's two clutches both failed as well. In his first clutch, both eggs appeared infertile, and in his second clutch, both eggs died from early embryonic death. Although egg fertility would not be affected by incubation diligence, there is a possibility that early embryonic death could. No data exist about the minimum threshold for incubation duration required on a nightly basis for successful hatching. The kiwi males that had successful fertilisation/hatchings in the study, Robin and Elmo, were also dedicated incubators with less nightly activity. Tuatahi was the least active of reproducing males during incubation, but unfortunately, his dedication was to an infertile egg.

With such a small sample size, it is inconclusive whether high activity levels affected egg

productivity, and I would recommend further study to test this. Malacarne et al. (1992)

ascertained that in pallid swifts (*Apus pallidus*) the higher the incubation effort, the greater

the breeding success. If a minimum threshold for sitting time is necessary and can be

established, then perhaps the eggs can be 'lifted' for artificial incubation if a male is not

meeting it. Fertile eggs could be potentially saved with pre-emptive measures or at least the

mating pair can try again.

3.4.4 Future recommendations

Assessing overall activity levels is a first step. Subsequent research should identify what

specific behaviours contribute to male kiwi activity and in what proportions. Identifying the

activity of reproductive males that corresponds with successful nests would be useful to

find the minimum incubation threshold. Populations that are intensely monitored for

reproductive outputs may consider such a minimum threshold valuable. Nests not meeting

this threshold would be predicted to most likely fail. Managers may then want to remove

the clutch to facilitate re-laying and/or artificially incubate the lifted clutch. Whether the

activity patterns of male *Apteryx mantelli* are characteristic of other kiwi species should

also be investigated. As some species have joint or group incubation, it would be expected

that they would have different activity rhythms.

Chapter 4- Female activity patterns of a fenced population of North Island brown kiwi (*Apteryx mantelli*).

4.1 Introduction

Within the physiological processes that ensure the growth, survival and reproduction of animals, feeding has the highest priority (Hanya, 2004; Itonaga et al., 2012; Libourel & Herrel, 2016) and rest is the second most important behaviour (Kurup & Kumar, 1993; Libourel & Herrel, 2016). Reproduction is necessary to ensure the survival of a species, but as it is often seasonal, it is not a constant tax on energy requirements. However, when the breeding season is occurring, behaviour often needs to adapt to the demands on both males and females. Although these demands may differ, each can be high. The allocation of various behaviours needs to balance the energy required for reproduction and survival so that neither sex is negatively affected.

North Island brown kiwi are nocturnal insectivores. Females are, on average, the larger sex (Reid & Williams, 1975; Robertson, 2003; Cunningham & Castro, 2011). In a breeding season females can produce up to three clutches and each clutch can contain one to two energy rich eggs. The astonishing aspect of brown kiwi reproduction is that each egg is between 15-20% of the female's body weight (Colbourne, 2002). Despite being of similar body size to a chicken, brown kiwi produce an egg with a mass roughly 350grams heavier (Calder et al., 1978). In addition, a brown kiwi takes twice the amount of time to produce one egg as a chicken takes to produce ten (Calder et al., 1978).

Although the males and females of some *Apteryx* species share incubation duties, in the majority of cases North Island brown kiwi males carry out all incubation (Colbourne & Kleinpaste, 1983; McLennan et al., 1987; McLennan, 1988; Burbidge, 2003; Robertson et al., 2011; Ziesemann et al., 2011). The paternal investment of the North Island brown kiwi frees up the female, but for what purpose? For a female of another ratite, the emu (*Dormaius novaehollandiae*), this relief from incubation allows a female to re-pair with a different male for her second clutch once her primary mate is occupied incubating her first clutch (Coddington & Cockburn, 1995). This type of polyandry has yet to be identified in North Island brown kiwi. Also, the energy requirements of producing such a large egg are undoubtedly great, and presumably would affect the behaviour of the bird carrying it in the breeding season. How does female behaviour change during and outside of periods of egg production?

Cunningham & Castro (2011) recorded that, regardless of sex, 75% of nocturnal kiwi behaviour was foraging, while the remaining 25% was spent on behaviours such as walking, vigilance, and comfort behaviours. For a female to produce such energy rich, large eggs it could be inferred that their energy demands would be greater than that of a male's and that foraging would need to make up a larger proportion of their daily activity budget to compensate. With reference to other behaviours, Colbourne & Kleinpaste (1983) documented male kiwi calling three times more than female kiwi. Theirs are the only published data that indicate a difference in activity budgeting between males and females. This limited knowledge of proportional female kiwi behaviour makes it difficult to understand the relationships and importance of individual activities.

The kiwi biology reviewed above suggests that there are gender specific differences in kiwi behaviour that may vary within and outside of the breeding season. Although I could never tell for sure that a female kiwi was gravid, the energy requirements to produce an egg suggest that a female kiwi would have to increase their foraging effort while producing an egg. For information about kiwi reproduction see Chapter 1. In this study I look at the timing and activity budgeting of female kiwi during and at the end of the breeding season; paying particular attention to the hours before and after dawn and dusk when transition from activity to inactivity (or vice versa) is expected to occur.

4.2 Methods

4.2.1 Field methods

This research was undertaken within the pest-free enclosures established at Maungatautari Ecological Island in 2008. See Chapter 2 for a description of the study area and its history. Before the start of the fieldwork, eight female North Island brown kiwi (*Apteryx mantelli*, henceforth 'kiwi') (Table 4.1) had been fitted with motion sensitive transmitters working on pulse rates of 30, 60, and 90 pulses per minute depending on bird activity (For transmitter details see Chapter 2). A mercury bead, imbedded in the transmitter, measured motion and inferred a kiwi's movements via a receiver.

Fragmented data resulted when kiwi ventured too far from a datalogger that had been left unattended. The Yagi aerial, which accompanied the receiver/datalogger, works on a line of sight. Dense understorey and a complex ridge and gully system can reduce the distance that the kiwi's signal can transmit to the receiver. Dataloggers were usually placed on the ground during the daytime when the female kiwi was in its burrow. The datalogger was not

always placed in the closest proximity to the bird; judgment, with regard to topography, was used about the area in which the kiwi was residing to obtain the strongest signal for the longest possible time.

A H.A.B.I.T (HABIT) Research Ltd. Osprey HR2600 receiver/datalogger ('Osprey') was used whenever possible to record the signal output that represented the female kiwis' activity. At each activity recording event, the Osprey was positioned to record an individual female kiwi, but was strategically positioned to cover an area where the kiwi might range. Dataloggers were usually positioned during the daytime when the female kiwi was in its burrow, but were not always placed at the closest proximity to the bird. Judgment had to be used when regarding the area where the kiwi resided, i.e. if the kiwi was situated in a gully, the datalogger would be placed high on the adjacent ridge so that if the kiwi ranged throughout the gully or up the opposite slope, the logger could still be within range.

Table 4.1- Female kiwi names, enclosure location, transmitter status, and breeding history. Breeding status is designated because females were known to be with incubating males but no genetic tests were done on eggs to confirm maternity.

Name	Enclosure	Transmitter duration	Breeding history
Cassidy	Northern	Dropped tx on 28Jan09	No known breeding attempts
Jo	Northern	Dropped tx 5 Nov08	No known breeding attempts
Karuwai	Northern	Continuous	No known breeding attempts
Pukupuku	Northern	Found and txd 6Feb09	1 egg produced and laid in July '08
Atua	Southern	Dropped tx on	1 egg produced and

		3Nov08	laid in Dec '08
Horokio	Southern	Continuous	Laid 2 clutches (4 eggs) in July & October '08
Te Mai e Po	Southern	Dropped tx on 28Jan09	Laid 1 egg in Oct '08
Te Rahurahu	Southern	Continuous	Laid 2 clutches (4 eggs) in Jul & Oct '08

A datalogger was usually able to receive 'in range' signals for longer when it was placed to 'look out' over an area from a high point or ridge. If a kiwi was out of range for long periods of time, signals would be transmitted less frequently, but would become more regular if the kiwi returned to the receivable area.

Recording lasted as long as the targeted kiwi was within range of the receiver/aerial setup, or until the receiver battery ran out, i.e. about 36 hours. The Osprey recorded: Date of transmission, time (in 24 hr format) the signal was transmitted, frequency being transmitted, and PPM or pulses per minute (30, 60, or 90). Often when a kiwi was out of range, a pulse rate would still be recorded by the receiver. However, the pulse rate received in this instance would be signified by any number, usually between 20 and 200, rather than at or around 30, 60 or 90. For graphing purposes all of these 'out of range' numbers were set to 100. The Osprey also recorded the percentage of signal strength which gave an idea of the proximity of the bird to the receiver/aerial setup when the signal was recorded. A low percentage indicated the kiwi was far away and vice versa. For example, a signal strength reading of 99% suggested the kiwi was within two metres of the receiver.

By the end of the study four of the eight females had 'dropped' their transmitters and one female who had been without a transmitter for three and a half years was found and refitted with a new transmitter (Table 4.1). Unfortunate events, such as kiwi losing their transmitters, lead to patchiness in data collection. Fragmented data also resulted when kiwi ventured too far from the datalogger or the Yagi aerial's line of sight was disrupted.

Once a datalogger was placed at what was thought to be the optimal position, it was left for roughly two days to record female kiwi signals. When possible, the female's signal strength would be checked on day two. If the datalogger was no longer receiving transmissions due to the kiwi's relocation during the night, it would be repositioned for further logging. When the datalogger's battery had run out, it would be retrieved from the field, charged, and all the information downloaded for analysis. It was then repositioned on another female.

4.2.2 Statistical analysis

Day & night, active & inactive

Total time spent active, inactive and out of range were calculated for those birds for which the in-range recording times exceeded four hours. When a kiwi was in range the activity/inactivity was calculated as a proportion of the total time a kiwi was recorded during the session. As some birds had multiple recording sessions, proportional activity/inactivity was averaged for each bird. Only when the in-range recording times exceeded four hours were the data used.

A Chi-square test was used to evaluate whether there was a significant difference between day and night on individual's activity levels (active vs. inactive). Pearson's correlation coefficients were used to determine the significance of the relationship between length of day and activity, and whether rainfall on previous days influenced activity (Rainfall data collected from a local farmer, Appendix 3). Univariate ANOVA was used to examine the effect of the individual on time active/inactive.

Pre-dawn & post-dawn, pre-dusk & post-dusk, active & inactive

I compared the activity of the females during the hour before and after sunrise and sunset (pre and post dawn and dusk). Statistical analyses were only carried out on birds whose recorded behaviour exceeded 30 minutes of the one-hour period. Birds with less than 30 minutes of recorded behaviour were filtered out. Equal variance, unpaired t-tests were used to look for differences in mean activity pre and post-dawn, and pre and post-dusk. Significance in individual female activity was tested using univariate analysis of variance. The relationships between average rainfall and activity in the pre and post dawn and dusk periods were tested using the Pearson Correlation Coefficient.

4.3 Results

4.3.1 Daytime & night time activity vs. inactivity

From 1 November to 28 February 2009, forty days of attempts were made to record the activity of eight different female birds. Of these 40 attempts, only 17 met the four-hour minimum requirement for the night time and 20 for the daytime. In all other instances the birds wandered out of range and insufficient activity information was received.

As expected female brown kiwi were, on average, proportionally more active at night than during the day (Fig. 4.1). Average proportional activity per bird ranged from 0.02-0.99 during the day (Fig.4.2) and 0.75-1.00 at night (Fig.4.3). During the day, individual birds had the same average activity levels (ANOVA; Daytime; n = 20, $F_{5,14}= 0.694$, $P= 0.636$). The same was true for night time activity where there was no significant difference in activity levels among individual birds (Night time; n = 17, $F_{4,12}=1.192$, $P= 0.363$).

There was no significant correlation between the proportion of night time that kiwi were active and length of night (r=-0.147, $P= 0.574$). Likewise, there was no significant relationship between day length and proportion of day active (r= 0.064, $P= 0.787$).
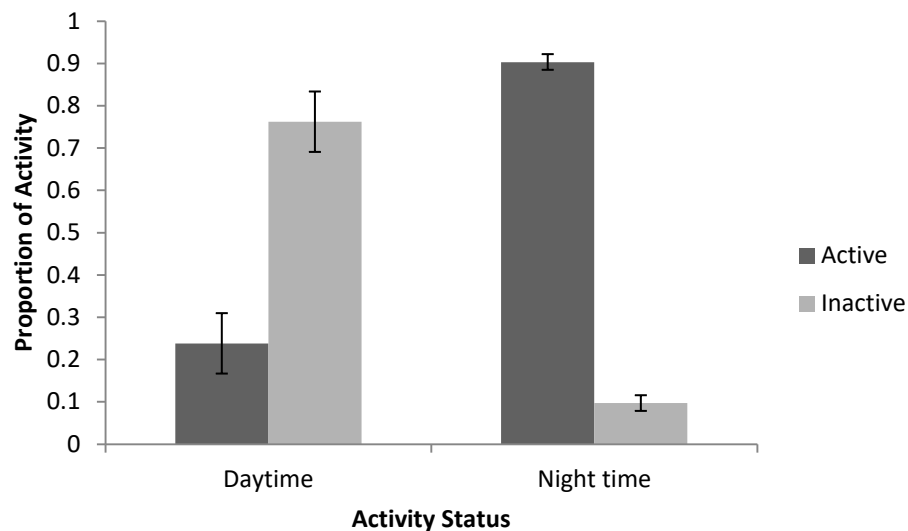
Fig. 4.1 - Mean proportional activity and inactivity of female kiwi during day and night time. Error bars are ± standard error.

There were substantial amounts of activity during the daytime (Fig. 4.4) with a few instances where individual females were very active (Fig. 4.2). For example, of the five

hours and 41 minutes of signal that I recorded during the daytime from Cassidy's transmitter, five hours and 39 minutes were active. In another instance, Karuwai's signal transmitted that she was active six hours and seven minutes of the six hours and 12 minutes I recorded. Although there was still a substantial portion of the day that the signal could not be recorded, this was still more time spent active than other birds. Substantial periods of inactivity were not observed during the night time (Figs. 4.3, 4.5). However, among individual kiwi the variation in inactivity during the night was significantly different (χ^2=3.58E+52, d.f. =1, P<0.001; Fig. 4.3) as was variation in the amount of activity during the daytime (χ^2=2.54E+68, d.f. =1, P<0.001; Fig. 4.4). See Appendix 1 (A1.1-A1.4) for more detail on individual female activity.
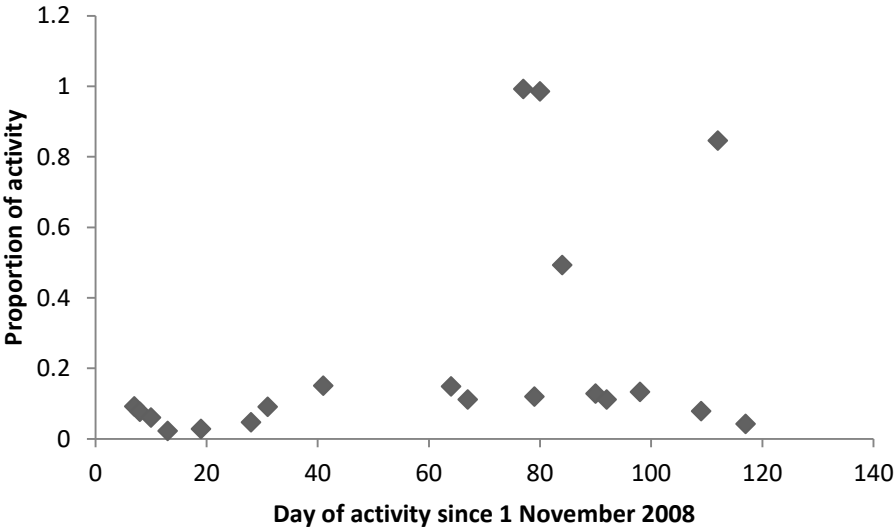
Fig. 4.2- All female kiwi individual proportion of daytime active from the beginning of November to the end of the study (28 February 2009).
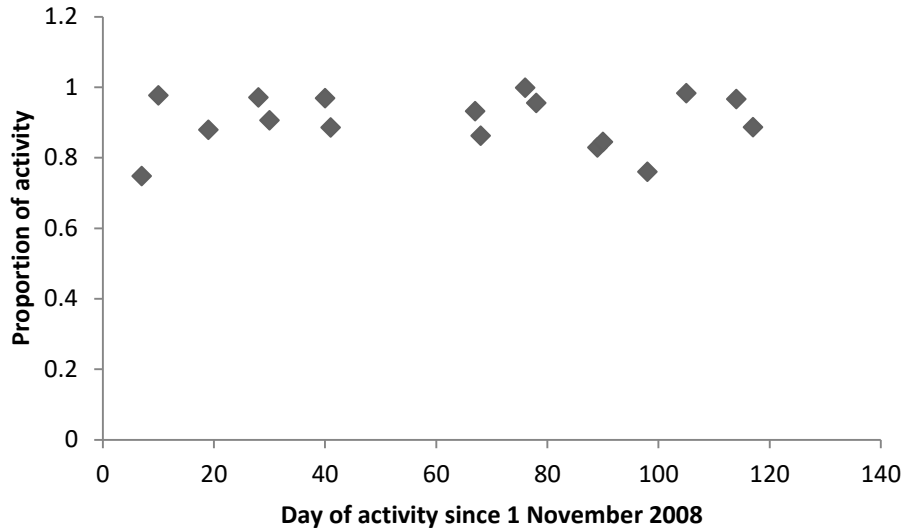
Fig. 4.3- All female kiwi individual proportion of night active from the beginning of November to the end of the study (28 February 2009).
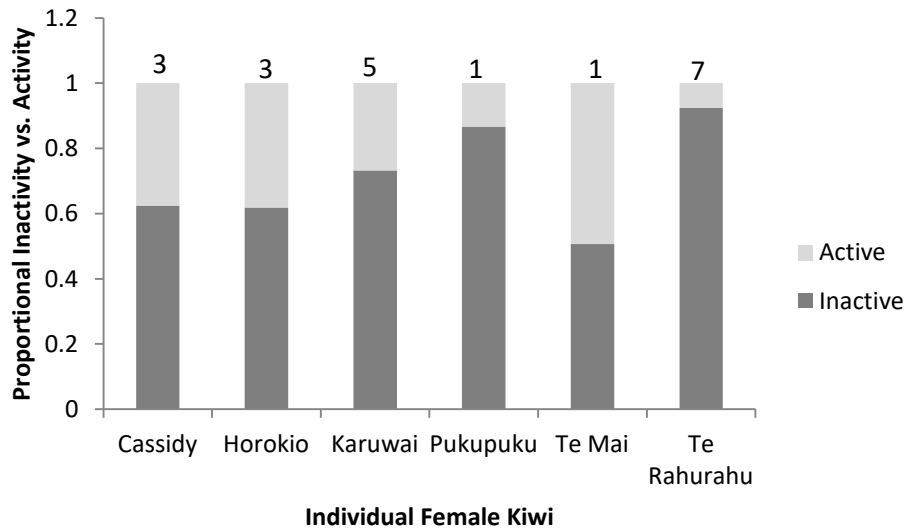
Fig. 4.4- Mean daytime activity vs. inactivity for different female kiwi at Maungatautari. Numbers above bars equal the number of times each bird was surveyed.
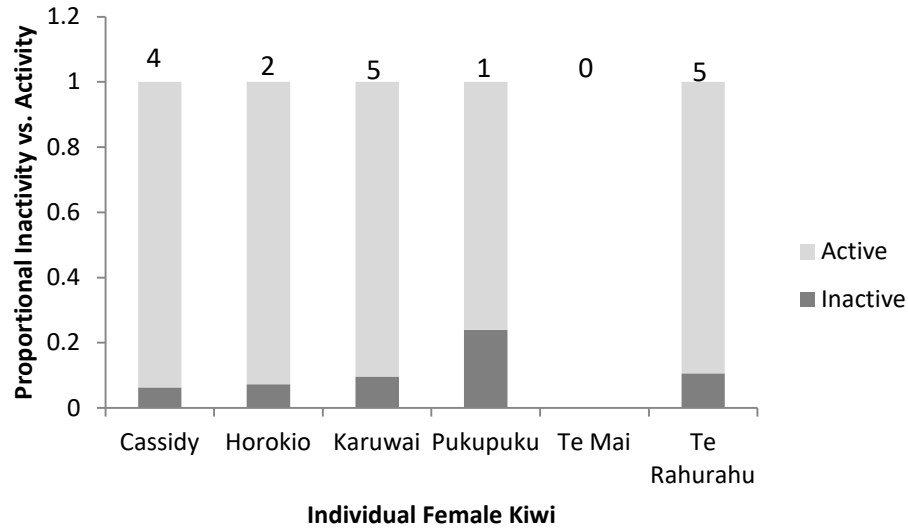
Fig. 4.5- Mean proportional night time activity vs. inactivity for female kiwi at Maungatautari. Numbers above bars equal the number of times each bird was surveyed.

4.3.2 Rainfall effects on activity

There was a trend toward increased daytime activity with higher amounts of rainfall in the four days leading up to the day observed ($r= 0.444$, $P< 0.05$; Fig. 4.6), however, there was no trend with respect to night time activity and rainfall.
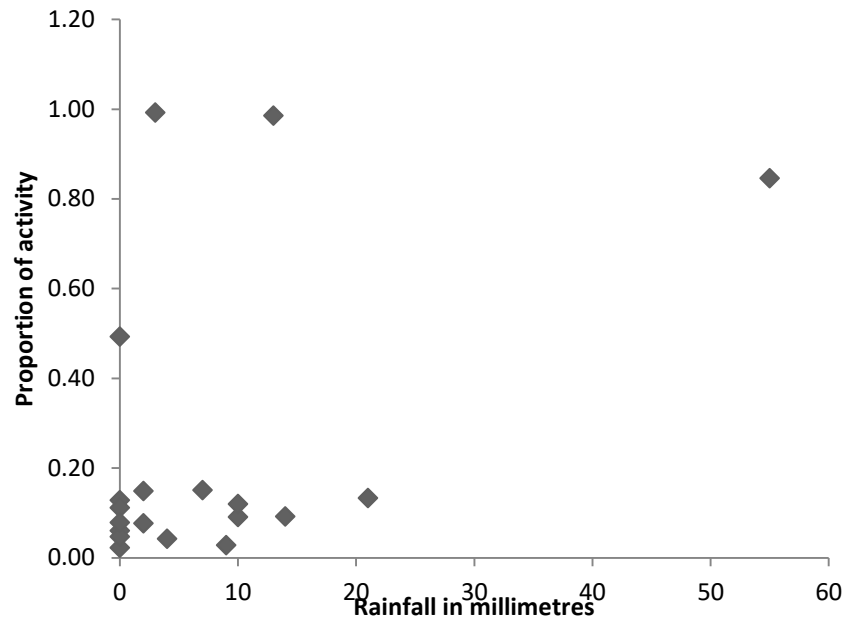
Fig. 4.6- Proportion of daytime active for individual kiwi compared to the cumulative rainfall (in millimetres) four days prior to, and including, day of activity. Proportional activity was not an average, but one bird's activity on that particular day. Note: Only one bird could be monitored per day.

4.3.3 Sunrise and sunset activity

There was a significant difference between one hour pre and post-dawn activity (t=2.162, d.f. =15, *P*=0.047) and a highly significant difference between one hour pre and post-dusk activity (t= -5.134, d.f. = 45, *P*= <0.001) when averaged across birds. On the whole, there was more activity pre-dawn when a kiwi would be expected to still be active, but still a surprising amount of activity post-dawn (50% of time) when a kiwi might have settled into a shelter (Fig. 4.7). The reverse was true at dusk when kiwi were surprisingly active in the hour prior to sunset. However, there was no significant difference among individual bird activities (Pre & post-dawn: F=0.238, *P*= 0.912; Pre & post-dusk: F=1.145, *P*=0.335). Despite there being large variation in differences in activity for single birds, all the single birds had this variation (Figs. 4.8-4.11).
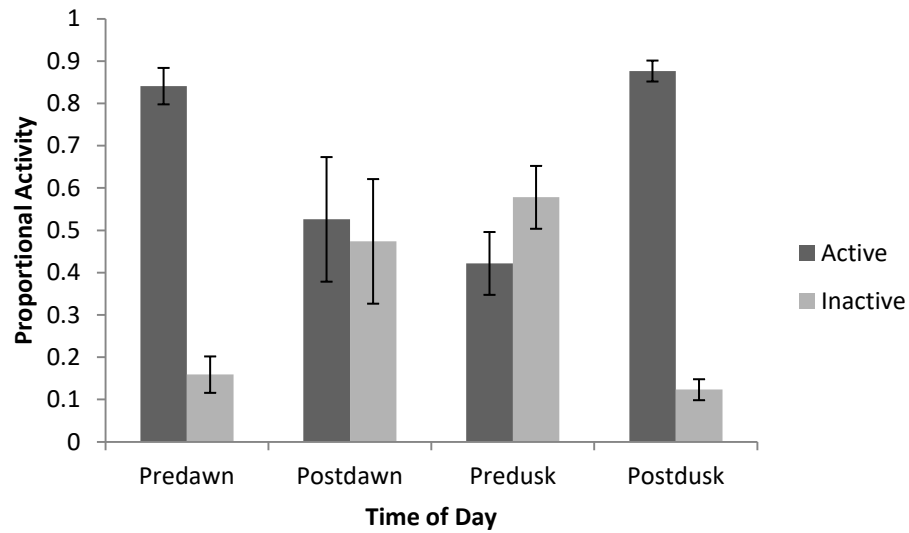
Fig. 4.7- Proportional activity and inactivity for pre and post-dawn and pre and post-dusk hours. Error bars are ± standard error.
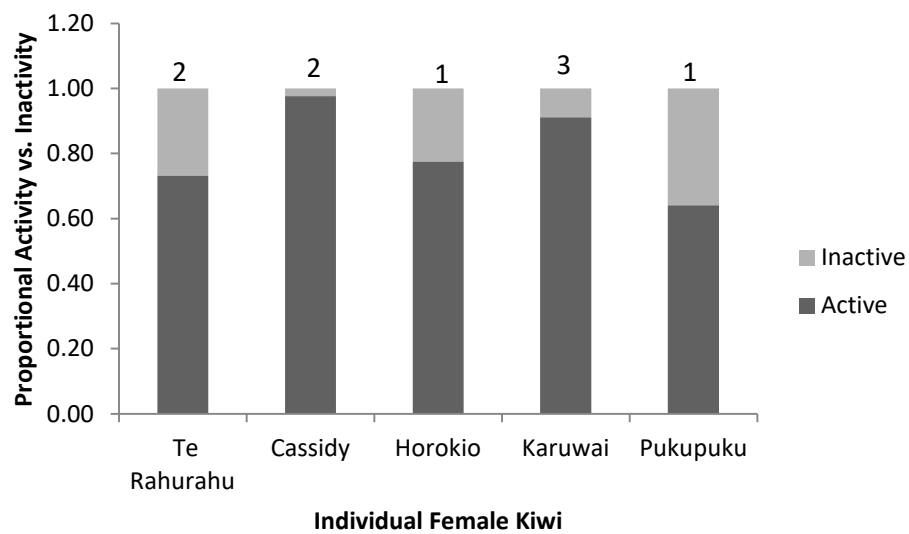
Fig. 4.8- Pre-dawn activity for individual female kiwi. Numbers above bars equal the number of times each bird was surveyed.
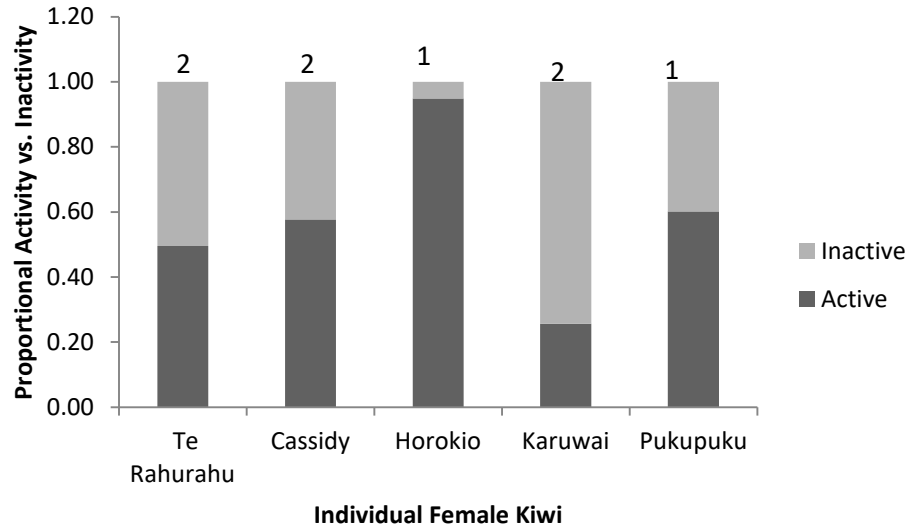
Fig. 4.9- Post-dawn activity for individual female kiwi. Numbers above bars equal the number of times each bird was surveyed.
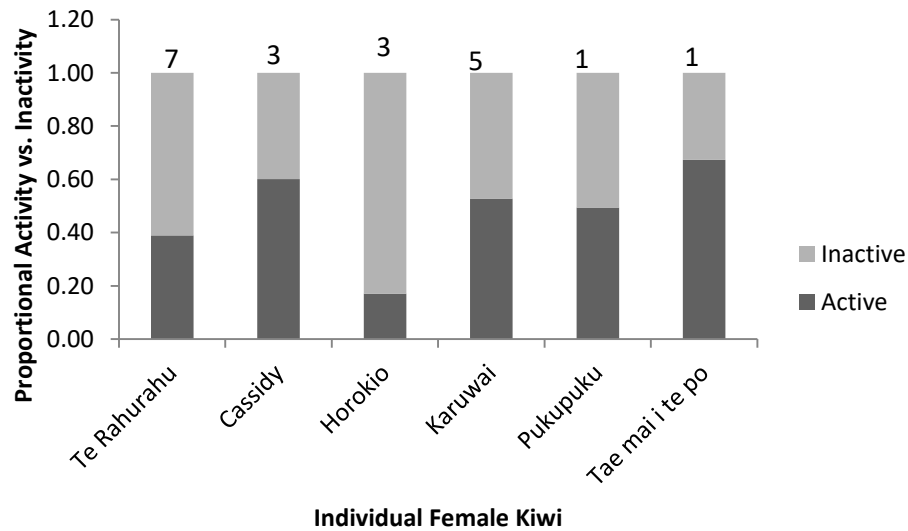
Fig. 4.10- Pre-dusk activity for individual female kiwi. Numbers above bars equal the number of times each bird was surveyed.
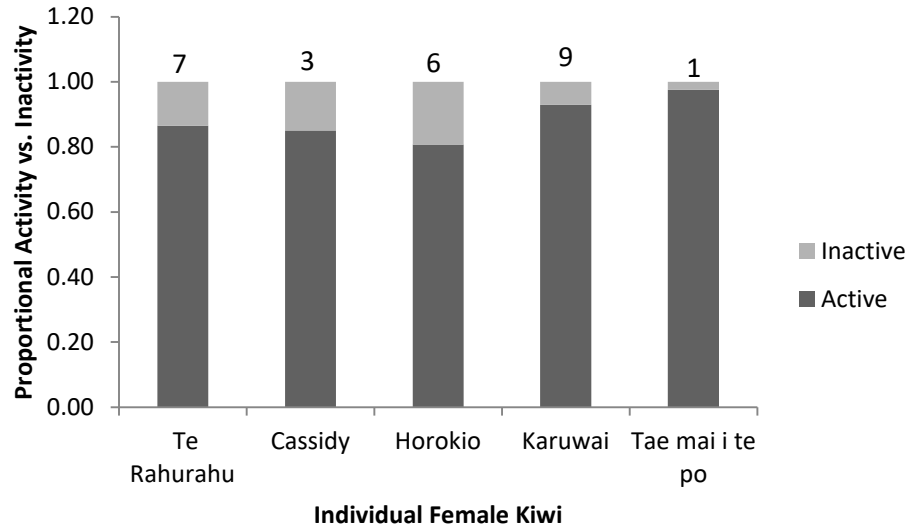
Fig. 4.11- Post-dusk activity for individual female kiwi. Numbers above bars equal the number of times each bird was surveyed.

4.3.4 Rainfall effects on sunrise and sunset activity

Rainfall had the greatest effect on activity in the pre and post dawn periods. Pre-dawn activity was significantly and negatively correlated with cumulative rainfall three days prior to ($r=-0.697$, $P= 0.037$), three days prior to and including the day of activity record ($r= -0.780$, $P= 0.013$), and six days prior to and including the day of activity record ($r= -0.694$, $P= 0.038$). The amount of post-dawn activity was significantly and positively correlated with cumulative rainfall over the six days prior ($r= 0.760$, $P=0.029$). There was no correlation of rainfall with pre and post dusk activity.

4.3.5 Transmitter signal strength fluctuations

The fluctuations in signal strength of the activity transmitters can be used as another indication of kiwi movement. Whether this movement takes place in or out of the shelter cannot be confirmed. Figs. 4.12 - 4.14 are examples of kiwi transmitter strength throughout

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the course of a day and night as further indication of behavioural patterns. These are examples of the three times that movement occurred during daylight hours where the signal strength readings fluctuated by large percentages. From on site field experience, smaller percentage changes are likely to be movement within the shelter. However, large fluctuations indicate that kiwi are moving closer to or farther away from the receiver, and thus, the kiwi's movement is most likely occurring outside of their shelter.
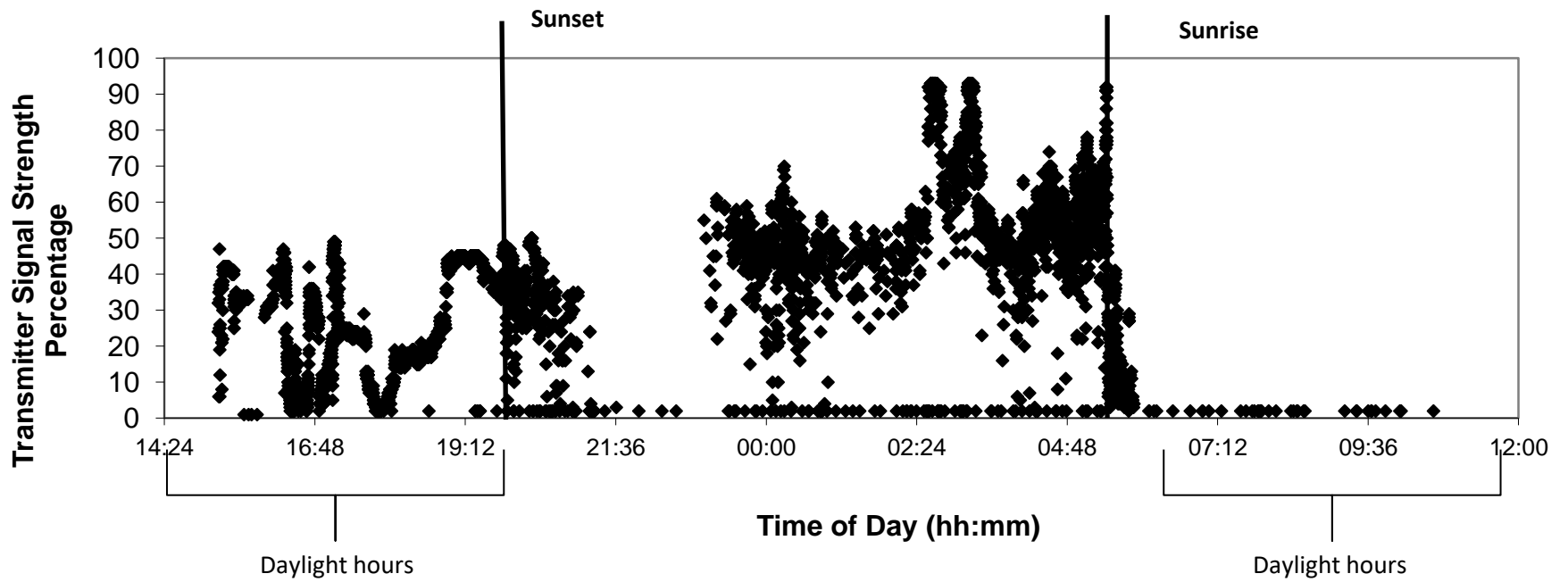
Fig. 4.12- Example of Karuwai's Transmitter Signal Strength from 10-11 November 2008. Note that during daylight hours the transmitter signal strength also fluctuates.
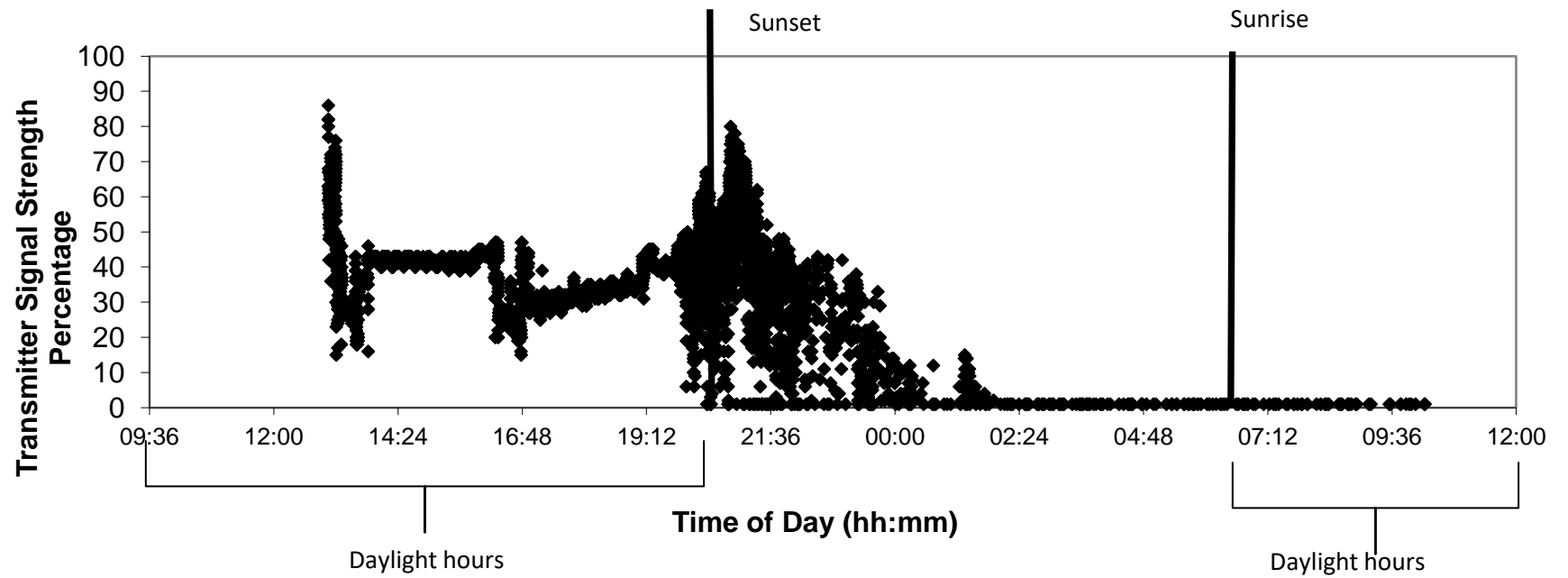
Fig. 4.13- Karuwai's transmitter signal strength from 25-26 February 2009. Please note the daytime movement away from the datalogger.
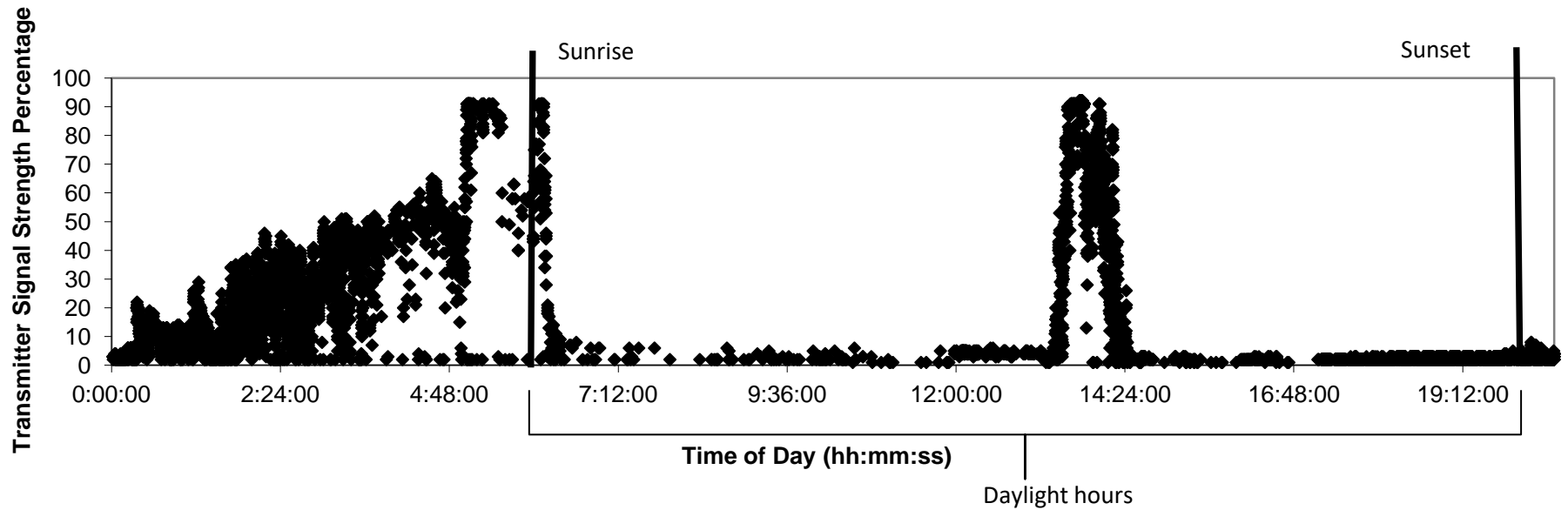
Fig. 4.14- Te Rahurahu's transmitter signal strength on 8 November 2008. Please note that at approximately 14:00 Te Rahurahu had movement which brought her very close to the datalogger and then she moved away again.

4.4 Discussion

To my knowledge, this is the first time a nocturnal bird's activity has been recorded over a 24 hour cycle. A search of the literature did not turn up any comparable study that might shed light on reasons for the behaviour observed.

4.4.1 Proportional activity

The proportion of time active per night for female kiwi in this study (during spring and summer) was not correlated to night length. This is in contrast with findings in Chapter 3 where I show that male activity fluctuated in relation to night length. In addition, at Maungatautari, female kiwi were, at times, active beyond the period of darkness (i.e., predusk, postdawn). As night time activity stayed reasonably consistent, the best place to look for changes in activity was during the daytime. One might expect that any behavioural functions uncompleted during the night would be 'carried over' into the day if necessary. This has been documented in other nocturnal species such as polecats (*Mustela putorius*) that incorporated diurnal feeding times into their daily activity patterns to potentially cope with increased nutritional requirements (Marcelli et al., 2003). If female kiwi spent the majority of the night foraging as Reid (1982) suggested, then behaviours such as preening or excavating could be making up daytime movement (Chapter 5). There is also the possibility that the additional activity is just more time spent feeding. On Stewart Island, New Zealand's third largest island, tokoeka (*Apteryx australis lawryi*) are seen foraging during daylight hours throughout the year (Colbourne & Powlesland, 1988). Reid et al. (1982) suggested that daytime feeding was the result of simply needing to forage enough to fulfil the dietary requirements of a larger bird, but Colbourne & Powlesland (1988) also hypothesised that limitations to prey availability (e.g., when soil is dry and difficult to probe) would also force kiwi to

extend their foraging efforts into daylight hours. In either case, fulfilling energy requirements may compel kiwi to extend their foraging into daylight hours and the same may be occurring for the Maungatautari kiwi.

4.4.2 Transmitter signal strength

Daytime feeding claims may be substantiated by the large fluctuations in transmitter signal strength observed during daylight hours indicating substantial movements. These fluctuations suggest that female kiwi activity during the day is not just settling in movements in the shelter at the beginning or end of the night. Time stamps synchronized with changes in signal strength suggest that some female kiwi are actively walking around during the middle of the day and sometimes for periods as long as 15 minutes. Whether this activity is born out of the necessity to increase foraging, the desire for a better shelter, or some form of disturbance within the shelter has not been determined. The enclosures that house the kiwi are open to the public and it is possible that human disturbance could be a factor in daytime kiwi movement as kiwi shelters have been identified next to public walking tracks.

4.4.3 Rainfall effects

Although rain events appeared to have no effect on night time behaviour, i.e. kiwi were active regardless, the females in this study were more active during the daytime if a rain event had occurred in the previous four days. Summer months can be a tricky time for kiwi as less frequent rainfall and warmer temperatures create dry soils which can make probing for invertebrates difficult (Colbourne & Kleinpaste, 1983). Successful feeding may be facilitated by soils that are easier to probe and rain events would aid this. A kiwi is expected to be active during the night and so an increase in rainfall during the

summer months may not have an effect on their night time proportional activity. However, during the daytime a kiwi may either take advantage of the softer soil to continue their foraging efforts or take the opportunity to perform other tasks that they did not get to during night due to a greater proportion of their time being occupied with foraging.

4.4.4 Pre & post dawn & dusk

A detailed look at the hours around dusk and dawn further highlight that the transition from active to inactive behaviour does not happen as soon as the sun rises or, the reverse, that kiwi do not become active the moment the sun sets. The inactivity in the pre-dusk/post-dawn hour could be attributed to the kiwi being asleep. Movement pre-dusk/post-dawn may be indicative of the kiwi need to get a head start on the evening's activities or to continue with unfinished business. If the kiwi did not have enough success feeding during the night, perhaps they continue their foraging efforts into the day. There is also the possibility of a 'waking up' or 'winding down' period. Shelter footage evidence (Chapter 5) documents kiwi becoming active within their shelter before heading out. As kiwi rarely used the same shelter twice, the 'winding down' period wasn't possible to film as I could not predict where a kiwi would shelter (unless they were nesting).

4.4.5 Rainfall effects on sunrise and sunset activity

Rainfall had the greatest effect on activity in the pre and post dawn periods. It would be logical to think that a bird would continue to feed given the opportunity of softer soils. As a kiwi would not have sampled the environment in the pre-dusk stage there would be limited reason to become active earlier in the evening. However, at the end of the night,

when a kiwi knows the feeding conditions, kiwi may extend their period of activity to take advantage of more probe-able soils. During summer months when precipitation can be unpredictable, any opportunities to increase physical condition from feeding would be advantageous.

Chapter 5- Are you sleeping? North Island brown kiwi (*Apteryx mantelli*) sheltering behaviour caught on film.

5.1 Introduction

Rest is essential for all vertebrates although the reasons for it remain unclear (Rechtschaffen, 1998; Steinmeyer et al., 2010; Libourel & Herrel, 2016). The length of rest can vary with gender, season, age and individuals (Steinmeyer et al., 2010) and 'rest' does not only include sleep; there are many waking periods within 'rest'. This 'rest' period can include a range of waking behaviours including preening, stretching, scratching, shivering, and vigilance (Siegel, 2005; Steinmeyer et al., 2010; Stuber et al., 2014). The evolutionary foundations of sleep are similar between mammals and birds, but otherwise sleep for birds is quite different with regard to function and pattern (Roth et al., 2006). Although sleep quality is similarly related to predation risk in birds and mammals, the function of sleep for energy conservation and memory consolidation in mammals is not apparent in birds (Roth et al., 2006). This suggests that more research is needed to understand the functions of rest and sleep in bird species.

North Island brown kiwi (*Apteryx mantelli,* henceforth 'kiwi') are a nocturnal bird (Colbourne & Kleinpaste, 1983; McLennan et al., 1987; Robertson, 1996) and therefore typically rest during daylight hours. A mystique around kiwi behaviour has arisen from their hard-to-view nocturnal activity which continues during the daytime as they tuck themselves away inside their shelters. Glimpses of kiwi lives have been observed using nest cameras or rare encounters at night, however, observer presence during encounters could have an effect on the latter behaviour observed. Any extensive filmed behaviour

is often of captive birds (Wesley & Brader, 2014), and only once has the footage been quantified and analysed for wild birds (Cunningham & Castro, 2011).

Behaviour, whether during the daytime or at night has implications for designing effective conservation management (Finlayson et al., 2008). Without knowing what kiwi do, managing them, whether it is to create a breeding population, maintain an existing population or enhance their habitat, becomes more difficult. If a kiwi spends a significant amount of time feeding in their shelter then the quality of the shelter becomes more important. This study investigates what kiwi do during the daytime rest periods by filming within shelters, and quantifies this behaviour while inside their shelters within the northern and southern enclosures of the Maungatautari Ecological Island.

5.2 Methods

Observations of kiwi within daytime shelters were carried out within the northern and southern enclosures of the Maungatautari Ecological Island in Waikato, New Zealand (see Chapter 2 for study site description) from July 2008 to February 2009. I attempted to film all kiwi (male, female, and incubating) within the study population in their daytime shelters at least once (Note: I did not include incubating males in the analysis) (for birds, equipment and recording details, see Chapter 2). The filming of birds was, at times, opportunistic, and locating paired birds was an unintended bonus. After locating a daytime shelter by following radiotransmitter signals, I placed the camera by reaching into the primary hole/tunnel and used the viewing monitor to locate the kiwi and the best position for filming. Once the camera was placed, I quietly backed away from the site and waited with the recorder, batteries and monitor which were attached by a cable

and set 20 metres from the shelter. I waited for the next five to ten minutes and using the viewing monitor I watched the kiwi to make sure it stayed within the camera's frame. If the bird bolted from the shelter during or immediately following the placing of the camera then a different bird was located and I, once again, attempted to position the camera for filming. If the kiwi remained settled, I left the equipment in place and recorded the daytime activity in the shelter. I then returned the following morning to collect the equipment and recharge the batteries. The 20 minutes of footage that immediately followed the placing of the camera was omitted from statistical analysis to allow for the kiwi to re-settle after any disturbance. All behaviour after the 20 minutes was considered 'normal' and included in analysis.

5.2.1 Video and statistical analysis

Not all birds in this study could be filmed and not all footage greater than 20 minutes was suitable for analysis. Footage was initially watched to determine the range of behaviours displayed and these behaviours were then categorised (Table 5.1). Once behaviours were determined, the video analysis consisted of watching all footage and recording, to the second, the amount of time spent engaged in different behaviours. Time spent on the different observed behaviours was summed per behaviour, and the total observed behaviour times in proportion to the total time the bird was filmed were calculated. On the three occasions that male and female kiwi were filmed sheltering together, the video footage was analysed twice; once to analyse female behaviour and once to analyse the male's behaviour.

Table 5.1- Observed behaviours of kiwi in their daytime shelters at Maungatautari with detailed descriptions of these behaviours and whether this behaviour was considered active or inactive.

Behaviour Observed	Description of Behaviour	Active or Inactive
Resting	Sleeping, sitting or standing with eyes closed or open. No movement occurring.	Inactive
Non-Specific Movement	Awake with eyes open. Behaviour includes head movements, yawns and twitches, but feet remain stationary.	Inactive
Stationary sniffing/tapping	Tapping of bill to ground or obvious sniffing. Bird appears alert. Feet are stationary.	Inactive
Mobile sniffing/tapping	Tapping of bill to ground or obvious sniffing. Bird appears alert and feet are in motion, i.e. walking.	Active
Self-Preening	Bird is preening the feathers on their own body.	Active
Mate Preening	Bird is preening the feathers on their mate's body.	Active
Feeding/Probing	Bird is sticking their bill into the ground and occasionally swallowing something as seen by a gulping movement in the throat.	Active
Other Movements	Movements include shifting, shuffling, scratching, excretions, excavating and any other movement that may activate their leg transmitter.	Active
Unseen Movement	Film is fuzzy or bird is too obscured to make out exact movement, but motion is seen.	Active

The proportion of time involved in each of the behaviours for each kiwi were entered

into a kiwi behaviour matrix. This was used to generate a similarity matrix of behaviour

among different kiwi using Euclidean distance as a similarity index. An ordination of these similarities was undertaken using non-Metric Dimensional Scaling (nMDS) to visualise the differences and similarities amongst different kiwi and by gender and singles versus couples.

An Analysis of Similarities (ANOSIM) was used to look at the significance of overall similarities/differences in behaviours for female and male kiwi, and single versus coupled birds.

Two-way Analysis of Variance was used to consider whether variations in individual behaviours were significantly different by gender (female versus male) and status (single versus couples). This was done for both broadly classified and more described behaviours.

For the birds whose footage was suitable, Levene's Test for Equality of Variance was run and, depending on the significance, unpaired sample t-tests with equal variances assumed or not assumed were used to discern any differences in proportional duration of behaviour between all singles versus all couples (regardless of gender).

5.3 Results

A total of 51 hours and 41 minutes of usable recorded video footage was taken of kiwi in their daytime shelters. Of that, 17 hours and 59 minutes was of six different kiwi alone in their shelters (Females= 11 hours 23 minutes; Males= 6 hours and 36 minutes) and 33 hours and 41 minutes was of three different male and female pairs sheltering together.

5.3.1 Shelter behaviours

During my observations, kiwi shifted, stretched, yawned, shivered, became startled, closed their eyes, stood up, sniffed the air, probed, ate, preened, defecated and excavated all while inside their shelters https://www.youtube.com/watch?v=TJlHLHQDGs8 . Individual kiwi showed considerable variation in behaviour. For example, Tuatahi self-preened in his shelter for 51 minutes out of nearly five hours caught on film. This was the most self-preening recorded by an individual bird. During two separate events, one pair of kiwi and one bird of another pair spent the majority of their time together in the shelter in an active rather than resting state (percentage of time recorded spent in an active state: Mark 77% and Atua 66%; Tari 63% and Jo 44%). Copulation was not observed between the coupled birds. Jo, a coupled female bird in another shelter, was filmed excavating the shelter for over five minutes. In this same filming session she stayed in her shelter nearly six and a half hours after sun down and almost five hours after her shelter mate had left for the night. This was unusual behaviour for a female kiwi (Chapter 4).

5.3.2 Couples versus singles

The placing of the camera was less likely to cause the exodus of the kiwi from the shelter if their mate was also present. All kiwi had longer filming times when they were sheltering with another kiwi. Out of 13 single kiwi filming events, seven events documented birds staying in their shelters for longer than 20 minutes but leaving the shelter prior to dusk. In two filming events birds deserted in less than 20 minutes. On the remaining four filming events the birds left at or near dusk. This contrasted with paired birds (three filming events), all of which did not leave their shelters until dusk or well after.

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Within the category of 'Other Movements' was the sub-category behaviour of defecating. Kiwi were filmed defecating in their shelters a total of five times. Three of those instances were by the female Pukupuku while she was sheltering with mate Tuatahi, and within the same filming session Tuatahi also defecated. Karuwai was the only other bird caught defecating on film.

5.3.3 New behaviours

To my knowledge this is the first time that the behaviour of mate preening has ever been reported. All couples exhibited mate preening whilst in their shelters and although it was, overall, not a statistically significant behaviour with respect to the amount of time observed mate preening versus the total time observed (t-test, t=-5.077, *P=0.091*), I note that in all three pairs the males preened the females more than the females preened the males (Table 5.2).

Overall, resting was the most common behaviour (mean proportion ± standard error (SE), 0.60± 0.07, Table 5.2) followed by Unseen movement (mean ± SE, 0.22± 0.01, Table 5.2).

Table 5.2- Mean proportion (± standard error) of the total time kiwi exhibited different behaviours. This is shown for male and female kiwi as singles or as couples during daytime sheltering.

Behaviour	Single ♀	Single ♂	Couple ♀	Couple ♂	Total overall
Resting	0.86± 0.04	0.51± 0.07	0.56± 0.17	0.34± 0.19	0.60±0.069
Non-specific Movement	0.08± 0.02	0.10± 0.04	0.02± 0.01	0.02± 0.004	0.06± 0.015
Stationary sniffing/tapping	0.01± 0.01	0.04± 0.02	0.04±0.03	0.04± 0.02	0.03±0.01
Mobile sniffing/tapping	0	0.004± 0.003	0.01± 0.01	0.02± 0.02	0.007±0.004
Self-preening	0.01± 0.01	0.04± 0.04	0.07± 0.04	0.06± 0.03	0.04±0.02
Mate Preening	NA	NA	0.01± 0.003	0.04± 0.02	0.01±0.01
Feeding/probing	0	0.04± 0.04	0.003± 0.002	0.003± 0.002	0.014±0.012
Other Movements	0.02± 0.01	0.03± 0.001	0.01± 0.003	0.03± 0.02	0.024±0.01
Unseen movement	0.03± 0.01	0.24± 0.08	0.29± 0.17	0.45± 0.2	0.22±0.01

The nMDS ordination of similarities of kiwi behaviour showed consistent variation between singles and couples, and between females and males (Figs. 5.1, 5.2). Analyses of Similarities in overall behaviours showed significantly different behaviours between couples versus singles (ANOSIM, R= 0.217, *P*=0.041, Fig. 5.1) and females and males (ANOSIM, R=0.253, *P*=0.012, Fig. 5.2).
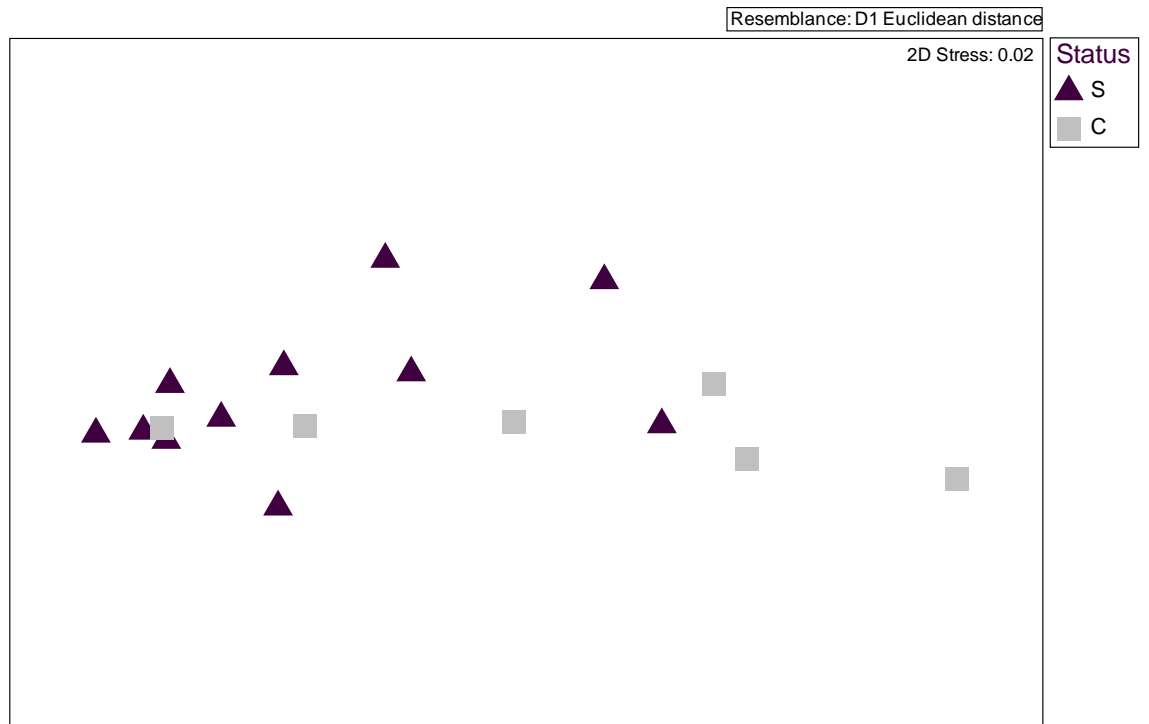
Fig. 5.1- A nMDS ordination diagram showing the similarities in the range of behaviours among single kiwi and coupled kiwi. S= Single kiwi, C= Coupled kiwi.
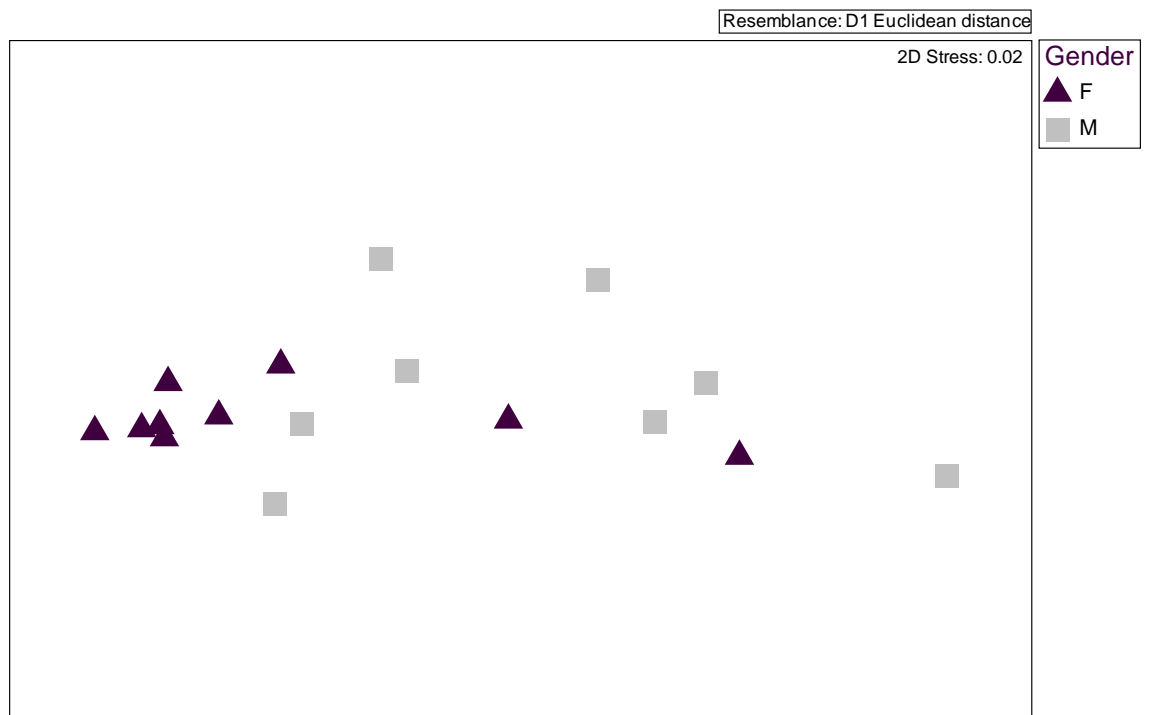
Fig. 5.2- nMDS ordination diagram showing the distribution of behaviours among female and male birds. F=Female kiwi, M=Male kiwi.

In terms of Active versus Inactive behaviours (Table 5.1), females had significantly

higher levels of % time inactive than males (mean ♀ 0.84 ± 0.08; mean ♂= 0.57 ± 0.07;

ANOVA, F=7.238, P=0.019). Single birds were also more inactive than couples (mean singles= 0.81± 0.05; mean couples= 0.53 ± 0.11; ANOVA, F=8.777, P= 0.011). Breaking down the inactivity into detailed behaviours observed (Table 5.1), single birds rested significantly more than coupled birds (mean single= 0.70 ± 0.07; mean couple= 0.45 ± 0.12; ANOVA, F=5.260, P=0.039) and female birds rested significantly more than male birds (mean ♀= 0.76 ± 0.007; mean ♂= 0.44 ± 0.08; ANOVA, F=7.728, P=0.016) (Fig. 5.3).
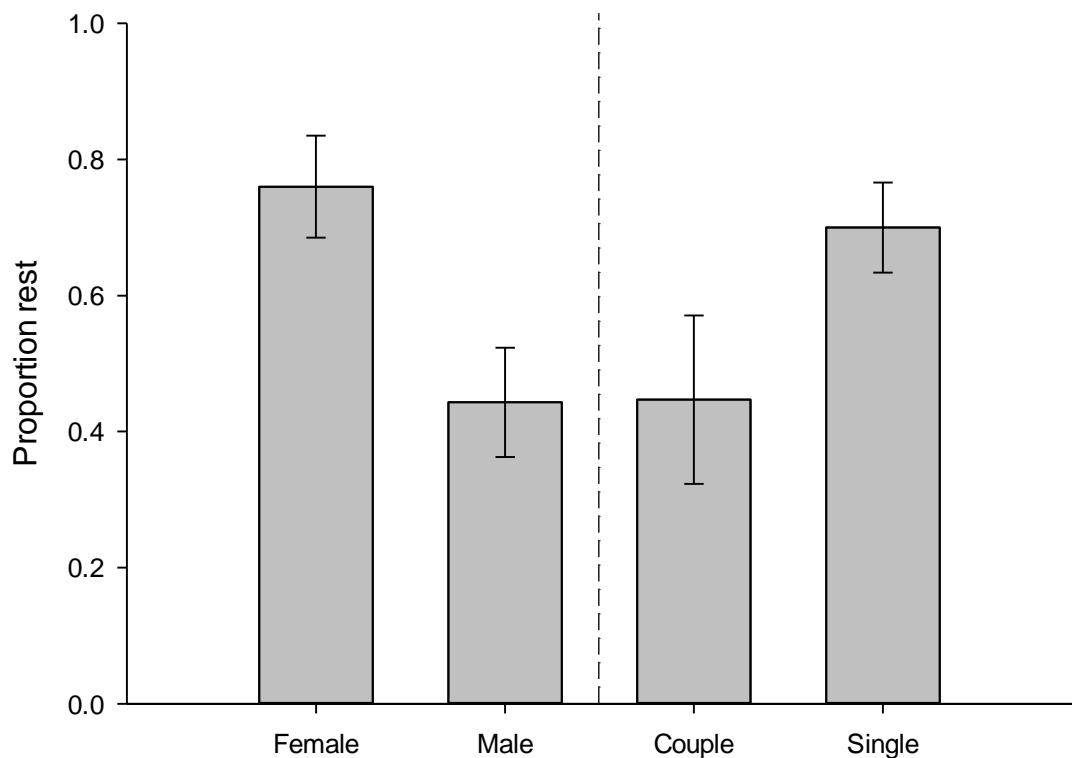
Fig. 5.3- Proportion of time kiwi rested in daytime shelters comparing females and males and coupled and single birds at Maungatautari.

Regardless of their gender, single birds had significantly more non-specific movement than coupled birds (mean ± SE single= 0.085 ± 0.017; mean ± SE couple= 0.021 ± 0.023; ANOVA, F=5.134, P= 0.041), but coupled birds had more unseen movement than single birds (mean couples= 0.370 ± 0.083; mean singles= 0.133 ± 0.062;

ANOVA, F=5.220, *P*=0.040). All other comparisons were non-significant between gender and social status.

5.4 Discussion

Some kiwi spent a considerable amount of time active in their shelters during daylight hours which leads me to conclude that kiwi do not use their shelters solely to sleep and they do more than just sleep during the day. Although many of these behaviours occurred infrequently, they may be still important in influencing kiwi survival, growth and reproduction. A healthy population is described by the Kiwi Best Practice Manual (Robertson et al., 2003) as a population with all age classes of kiwi. The manual also describes "good condition" scores and halting declines. Recording activity budgets and specific behaviours are more intensive monitoring techniques, but sub-sampling populations could be useful to know how kiwi are responding to management regimes.

5.4.1 Gender and single versus coupled kiwi behaviour differences in daytime shelters
The ordination results showed that overall, the range of behaviours between single and coupled kiwi were significantly different and even more so between female and male kiwi. As this study was based around the breeding season, behaviours between male and female kiwi would differ because each gender has a different function (Weathers & Sullivan, 1993), i.e. the females are producing an egg which the male will then incubate. Regarding the behaviour of resting, not only were single females recorded resting more than single males but coupled females rested more than coupled males. Note that the terms single male and single female means only that they were alone in the shelter at the time of filming. This does not mean they were not part of a pair bond or in egg production. Egg production takes roughly 34 days (Taborsky, 1994) and during and

after this time it would be expected that a female would need food, rest, and recovery to produce an egg and following egg laying to recover condition (Steinmeyer et al., 2010, Askenmo et al., 1992). Three of the four birds observed individually in their shelters produced one to two clutches. The remaining female was known to shelter with a male bird but was not known to have produced any eggs. All three of the 'single male' kiwi observed were also observed as 'coupled male' birds. The mean proportional rest of 'single males' was greater when they were alone than when they were coupled. Kiwi sheltering as a couple are presumably engaged in pair bonding, so a higher level of activity could be anticipated. Steinmeyer et al. (2010) study of blue tits (*Cyanistes caeruleus*) showed that not only is sleep duration shorter during the breeding season, but that sleep behaviour is gender dependent with females having overall more wake time during their resting period despite males going to sleep later and waking earlier. Consistent variation among individuals was apparent and was also observed with the Maungatautari kiwi.

5.4.2 Kiwi couples

Kiwi found sheltering as couples often provided useful lengths of footage to view. An undocumented number of kiwi filmed sheltering alone deserted their shelter during the camera setup process which was most likely due to disturbance resulting from the placing or presence of the camera equipment. Paired kiwi did not have the same reaction. None of the paired kiwi deserted leading to the conclusion that the need for pair bonding anchored the birds to their location.

Kiwi opting to defecate in their shelters when coupled with their mate may be another example of the importance of pair bond maintenance on Maungatautari. Karuwai, a

'single female', was filmed defecating in her shelter and although this is a common behaviour in some populations (I. Castro, pers.com.) this was the only time it was exhibited at Maungatautari by a 'single' kiwi. Pukupuku's repeated defecations and Tuatahi's single evacuation inside the shelter could be an example of a pair of birds being anchored to a site while together. On Ponui Island kiwi, who repeatedly re-use their shelters, have been known to defecate in them (I. Castro pers. com.). Other studies have found repeated defecations in a core area of the animal's habitat to be a sign of predator avoidance (Zeide et al., 2016) and/or guarding of the breeding area (Roper et al., 1993), While the reason for this may be to mark the shelter as 'theirs', a pair may defecate in the shelter so to not be separated from each other. As the only instance of kiwi re-using their shelters was observed for paired birds (Chapter 7), Karuwai's reason for defecating in her shelter is unknown. She may have intended to re-use the shelter at some point in the future, or she avoided leaving the shelter for some behavioural reason. Note: She did back up toward the shelter entrance (and camera) before ejecting.

Mate preening was a behaviour exhibited by all three couples in this study and yet it has never before been recorded in the kiwi literature. Interestingly, the male kiwi were observed doing the majority of the mate preening. In one incident there was footage of the male bird Tuatahi a Nui preening his mate's cloaca. Oxytocin release, activated by tactile stimulation, has been linked to regulating pair bonding in some species (Svec et al., 2009; Johnson et al., 2015). Preening of the female by the male could be an example of the male investment in the pair bond, i.e. securing the female's favour and therefore the potential for future offspring. There are many instances of allopreening in other birds including the common hill mynahs (*Gracula religiosa*) (Archawaranon, 2017),

common murres (*Uria aalge*) (Takahashi et al., 2017), and king quail (*Coturnix chinensis*) (Adkins-Regan, 2016) and all have a social function.

Some pairs remained faithful to each other in the breeding season following this study, but others, i.e. Tae mai, Puke, Jo and Tuatahi, were subsequently found sheltering or had mated and produced chicks with other birds (M. Lamas, pers. com.). Jo and Tuatahi produced a chick together, but afterwards Tuatahi returned to his previous mate Pukupuku.

5.4.3 Shelter behaviours

Jo, the female bird filmed excavating her shelter, was the largest of all the birds in this study (3.65kg). Jo was also in this shelter with her potential mate at the time she excavated. Whether she was excavating this shelter because she was a large bird and needed more space or perhaps because she was preparing a nest was unclear. I have not come across any observations as to which sex is the maker of the nest, and as no known egg was produced from this union, I can make no further claims. If Jo intended to re-use this location as a shelter then the investment in alterations is logical. As previously stated, Maungatautari kiwi were almost never recorded re-using their shelters, which may explain why excavating was not a behaviour more regularly seen. A shortage of shelters would make those available more desirable and an effort to retain and enhance a shelter would be expected i.e. defecating in it and excavating. The apparent abundance of potential shelters that occur on Maungatautari (Chapter 7) suggests that this behaviour is unnecessary.

5.4.4 Unseen and non-specific movements

Kiwi shelters could be large networks with multiple entrances and levels (Chapter 7). In some complex shelters I observed kiwi moving from 'chamber to chamber'. In contrast, other shelters were small holes with a single entrance. In both scenarios, behaviour could be difficult to record. Inside one chamber shelters kiwi often positioned themselves with their back to the entryway. Much of their behaviour was small and recorded as 'Non-specific Movement' which is why single birds had significantly more of this behaviour classification. In footage of paired kiwi, often one bird would obscure the other. It was apparent that movement was taking place but it was difficult to determine how to classify behaviour which is why coupled birds had significantly more 'Unseen Movement'.

'Shivering' was a non-specific movement that kiwi frequently exhibited. Kiwi, like other endotherms shiver to compensate for cool temperatures (Erikson et al., 1956; Wallis, 1979). Although this behaviour was not logged separately, I observed (understandably) more shivering during the cooler months and less shivering when kiwi were sheltering together. The added insulation from close proximity of coupled kiwi may have rendered shivering unnecessary. With this added benefit of pair bonding I'm surprised I didn't find kiwi sheltering together more often during the cooler months. Less chance of rest, however, may have reduced coupling frequency. Interestingly, Opp et al. (1987) found that shivering never occurred when his gull subjects were having 'closed eye' rest. Although not quantified, the Maungatautari kiwi were seen shivering when in a 'sleep' state (eyes closed).

5.5 Conclusions

Kiwi use their shelters primarily for resting but there is a level of activity within shelters that, although it is variable, is undeniable. Activity within the shelters significantly increased when kiwi were with a mate. This study documented the first known record of mate preening. Successful reproduction may be dependent on the behaviour both when in a couple and when alone in the breeding season. Sufficient pair bonding to stimulate copulation and the rest required to develop and care for potential offspring should be expected as part of kiwi behaviour.

Chapter 6 - North Island brown kiwi (*Apteryx mantelli*) home range size and distribution within two pest proof enclosures on Maungatautari Ecological Island.

6.1 Introduction

The active exclusion of conspecific individuals from an area is what distinguishes a territory (exclusion) from a home range (no evidence of exclusion). Whether the exclusion is affected by scent marking, calling or aggressive behaviour, the main purpose is to deter conspecifics from making a claim on an area (Noble, 1939; Burt, 1943, McCoughlin et al., 2000). To predict how animals will use a space one must first understand the driving factors behind their spatial use (Moorcroft, 2012). Within a home range a species carries out activities such as food acquisition, mate bonding, copulation, and the rearing of offspring (Burt, 1943), but as opposed to a territory, a home range may be shared with others. Food availability, as it plays an important role in survival and reproduction, is a habitat characteristic that would affect the behaviour of animals and how they organise themselves within an area (Elmhagen et al., 2014). Food availability is also seasonal and may change animal behaviour throughout the year (McCoughlin et al., 2000; Schradin & Pillay, 2006). It seems likely that the spatial distribution of food availability may be a significant driving factor in determining home ranges.

Movement by a species throughout a home range or territory is usually structured to try and maximise food resources acquired. Conspecific overlap is common amongst many species as it is natural to test territorial borders. Scent marking and vocalisations can be less aggressive strategies for defending a territorial border as avoiding altercations with neighbours is desirable (Potts & Lewis, 2014).

The size of a home range or territory for any animal can be affected by a number of factors such as food quantity and distribution, habitat quality, the availability of shelter/nest sites, total area and the density of competing individuals (Colbourne & Kleinpaste, 1983; McLennan et al., 1987; Taborsky & Taborsky, 1995). Proximity to a water source may contract a home range (Smith & Griffiths, 2009) while animals with higher energetic needs, whether it be because they are larger or reproducing, may need larger areas to accommodate energy requirements (Stanner & Mendelssohn, 1987). Variable home range and territory sizes have been estimated for the North Island brown kiwi (*Apteryx mantelli* henceforth 'kiwi') for different populations (Colbourne & Kleinpaste, 1983; McLennan et al., 1987; Taborsky & Taborsky, 1992; Ziesemann, 2011). In Northland, New Zealand, a place known to have relatively dense populations of kiwi, the average home range is five ha/pair (Colbourne & Kleinpaste, 1983; Potter, 1990; Taborsky & Taborsky, 1992) and home ranges are even smaller still on Ponui Island where a kiwi home range is roughly three hectares (Ziesemann, 2011). At Lake Waikaremoana, kiwi populations have been about one bird/100ha (McLennan & Potter, 1992) and territory sizes have ranged from 19 to 48 ha/bird (McLennan et al., 1987). In Tongariro where the average kiwi density is one pair/100 ha, size was even larger (Colbourne et al., 2005; Miles et al., 1997). Range/territory sizes can fluctuate seasonally as Ziesemann (2011) reported contracted home range sizes of male kiwi during the breeding season, while female kiwi home ranges were, in fact, slightly larger. Other studies have shown female kiwi to have larger territories than males, but it was unclear whether this was during or outside of the breeding season (McLennan et al., 1987; Potter, 1989; Taborsky & Taborsky, 1992).

Potter (1990) discussed the need for increased management when kiwi are living in less than optimal sized areas, and recommended that at least 750 ha of habitat were appropriate sized areas for populations of 500 kiwi. This advice was estimated from population density data based on open area reserves with on-going predator control (Potter, 1990). On island populations that are a safe distance from land with predators, the sea provides the protection against predation but is also the overall restrictor of kiwi home range expansion. Many current conservation projects are adopting pest proof fences as their means of permanently excluding potential predators (Burns et al., 2012). A fence, however, creates a barrier not only preventing immigration, but emigration. Should resources such as food and shelter become limited within a fenced enclosure, area will eventually constrain the population density (Hayward & Kerley, 2009). A fenced enclosure can also give rise to abnormal behaviour in the form of stereotypic pacing. This behaviour, most commonly demonstrated by zoo animals (Mallapur & Chellam, 2002), could result in kiwi disproportionally favouring the edges near the fence lines thus changing the way a kiwi uses the enclosure. All published kiwi spacing behaviour work has been carried out in open area reserves and on islands, but the effects of limiting their range with an enclosure fence on population carrying capacity is unknown.

As previously stated, resource availability affects territory and home range sizes, so knowledge of spacing behaviour and habitat use becomes important for establishing an area's carrying capacity. Colbourne & Kleinpaste (1983) relayed the importance of marshy areas for kiwi to feed in during droughts, but how do kiwi also utilise their home ranges with or without the presence of water courses?

This study investigates two small populations of kiwi within fenced areas and asks:

1.   How do the kiwi at Maungatautari use space within the limited area of the fenced enclosures?

2.   How do paired and unpaired males and females partition these areas and what is their overlap with their mate and other conspecifics?

3.   How do kiwi move through their home range over the course of time?

4.   What importance do kiwi place on water courses within the enclosures?

6.2 Methods

6.2.1 Field methods

Prior to this study, the kiwi in the enclosures had been fitted with radio transmitters each tuned to a unique frequency (Chapter 2). The transmitted signals were picked up using a TR-4 or a H.A.B.I.T Research Ltd. Osprey HR2600 receiver/datalogger coupled to a Yagi antenna (Chapter 2). As I have no evidence that kiwi were actively defending the area they occupied, I have chosen to use the term home range rather than territory. Home ranges were estimated using the locations of day-time shelters. During daytime hours from July 2008 to March 2009 I opportunistically identified individual kiwi signals and followed the signals until I could positively identify the daytime shelters where the various birds were resting. Shelter locations were recorded by referencing the tracking tunnel grid systems already established within the enclosures because frequent poor satellite coverage introduced large GPS errors (Chapter 2). As all coordinates for tracking tunnels had been previously established with considerable accuracy (Figs. 2.3, 2.4), shelter location co-ordinates could be ascertained by GIS post-fieldwork. Notes on

where individual kiwi were ranging were also made during night time observational work.

6.2.2 Data analysis

Ranges 8 (Anatrack Ltd.) (Kenward et al., 2008) was used to analyse kiwi location points obtained from radio telemetry. Home range assessments were only determined for birds with more than five recorded shelter points. Home range estimates were calculated using Minimum Convex Polygons with 100% cores (McLennan et al., 1987) and re-calculated arithmetic mean (ac= centre of activity). As this analysis can be inclusive of areas not used by kiwi, concave polygons were also calculated, with selected edge restriction and corner cell polygons, to calculate home ranges while eliminating outer edges. Minimum convex and concave polygons are reported as mean ± standard error.

I examined the home range overlaps between birds using Ranges 8 and Harmonic Mean Contours analysis (based on the inverse reciprocal) to estimate the area (in hectares) an animal used with the most intensity. I used Levene's test for homogeneity, and transformed the data, when necessary, to achieve homogeneity of variance. I also used the Shapiro-Wilk test to evaluate data for normality and once normality was confirmed, I examined the effect of sex (male, female), location (northern enclosure, southern enclosure) and incubation status (incubating, not incubating) on home range sizes and harmonic mean contours using ANOVA.

Shelter locations for all kiwi were mapped using GIS. The distances between shelters and the closest known water source were calculated and compared with a distribution of

random slope midpoints. T-tests were then used to assess whether kiwi shelter locations were closer to water sources than would be expected by chance. I also calculated the distances between shelter sites used on consecutive days to estimate the minimum distance travelled by kiwi in a night and used t-tests to compare this variable amongst all northern versus all southern enclosure birds, all males versus all females, and males and females within each of the enclosures.

Using Levene's test, time series overlap data were assessed for homogeneity of variance. A Repeated Measures Analysis of Variance was then used to look at the effect of enclosure, gender, and gender within each of the enclosures on overlap of kiwi. The identity of the bird was used as a repeated measure. Overlap results were further explored using unweighted means to tease out the influence of these effects using a significance level of P= 0.05. All tests in this chapter were carried out using Statistica v.9 (Statsoft Inc, 2009).

6.3 Results

6.3.1 Home range analysis

All data were normally distributed (Shapiro-Wilk test, all *P*>0.05), but due to the low number of shelter locations recorded for two northern enclosure females (< 6), their home range statistics were omitted from further analysis. An incremental plot analysis showed that estimates of home ranges for all kiwi excluding one of the females (Jo) did not always reach asymptotes (Table 6.1) suggesting that some home ranges were slightly underestimated.

As there were similar results for both convex and concave polygon methods, I will just report the convex polygon method. There were significant differences in home range sizes between all males and females from both northern and southern enclosures together (t-test: mean ♂= 9.74 ha ± 1.36 ha, n = 7; mean ♀= 15.63 ha ± 2.09 ha, n = 6; t= -2.43, *P*=0.03; Table 6.2). There were significant differences in home range sizes between males and females in the southern enclosure alone (mean ♂= 8.22 ha ± 1.24 ha, n = 4; mean ♀= 17.28 ha ± 1.41 ha, n = 4; t-test, t= -4.83, *P*< 0.01), but not between males and females in the northern enclosure alone (mean ♂= 11.77 ha ± 2.51 ha, n = 3; mean ♀= 12.32 ha ± 6.08 ha, n = 3; t-test, t= -0.10, *P*=0.93). There was no significant difference in home range size between birds of both sexes when comparing northern and southern enclosures (northern mean= 12.75 ha ± 1.919 ha; southern mean= 10.54 ha ± 2.42 ha; t-test, t= 0.73, *P*= 0.48). Likewise there was no significant difference in home range sizes between incubating and non-incubating males across both enclosures (incubating mean= 8.23 ha, SEM= 0.96; non-incubating mean= 13.54 ha ± 3.09 ha; t-test, t= -2.32, *P*= 0.07).

Levene's Test of Homogeneity of Variances on the harmonic mean contour data was highly significant (P = 0.001) for southern enclosure males and females, therefore, these data were transformed using natural logs (ln) which achieved variance homogeneity. Using these transformed data, southern enclosure males' area of intensive usage was significantly smaller than southern enclosure females (mean ♂= 0.14 ± 0.38; mean ♀= 1.81 ± 0.42; t-test, t= 2.94, *P*= 0.03). No difference in area usage was found between males and females in the northern enclosure however (mean ♂= 3.45 ± 0.91; mean ♀= 2.70 ± 1.52; t-test, t= 0.46, *P*= 0.68).

Table 6.1- Incremental Plot Analysis. The minimum convex polygon (in hectares) calculated for each kiwi as number of observations increases.

No. of locations	Atua	Horokio	Te Rahurahu	Tae mai	Parure	Robin	Elmo	Mark	Tuatahi	Tari	Puke	Karuwai	Cassidy	Pukupuku
3	4.32	0.2	1.74	0.92	0.51	0.43	0.11	0.83	0.17	3.26	1.12	1.92	0.29	2.87
4	6.45	0.21	3.97	2.23	1.93	0.54	0.72	2.59	0.24	3.26	1.32	1.92	2.73	2.9
5	9.11	0.22	4.94	3.67	3.17	1.05	2.65	5.13	1.92	7.16	1.32	2.41	3.51	3.26
6	11.25	0.34	4.94	3.98	3.43	1.11	3.41	9.47	2.16	7.46	3.52	2.51	5.89	
7	11.44	2.1	5.11	4.47	3.43	1.88	3.59	9.47	2.3	7.98	7.22	2.91	7.56	
8	11.44	2.15	5.11	4.72	3.43	2.55	3.63	10.06	4.33	8.16	7.22	3.9	9.06	
9	11.44	2.15	5.22	5.05	3.43	5.14	3.65	10.06	4.33	13.89	8.35	3.9	9.06	
10	15.93	2.15	5.22	5.05	4.41	5.32	3.68	10.21	4.33	14.43	8.77	4.05	11.19	
11	16.74	2.73	6	5.56	5.86	8.83	3.68	10.21	4.33	14.45	10.07	4.05	16.4	
12		4.3	6.71	11.58	5.86	8.84	6.45	10.31	5.62	15.57	10.14	4.85	16.4	
13		4.3	6.93	14.41	5.86	9.41	6.45	11.04	5.93	15.57	10.45	4.85	17.03	
14		4.68	8.03	14.41		9.53			6.05	16.62	10.45	4.85	18.4	
15		4.68	13.89	14.41					6.05		10.45	4.85		
16		6.77	13.89	14.45					7.13			6.2		
17		6.77	13.9	20.72					7.76			6.2		
18		6.85							8.25					
19		6.85							8.25					
20		12.74												
21		16.14												
22		17.54												
23		17.54												
24		17.76												

Table 6.2- General information and home range sizes for individual birds using Minimum Convex Polygons and Concave Polygons. F=female; M=male

Kiwi individual	Enclosure	Gender	No. of locations observed	Minimum Convex Polygons (ha)	Concave Polygons (ha)
Atua	Southern	F	11	17.81	11
Horokio	Southern	F	24	18.76	13.86
Te Rahurahu	Southern	F	17	14.8	10.67
Tae mai	Southern	F	17	21.93	16.73
Parure	Southern	M	13	6.42	4.94
Robin	Southern	M	14	10.34	5.56
Elmo	Southern	M	13	7.03	3.3
Mark	Southern	M	13	11.89	7.75
Tuatahi	Southern	M	19	9	6.71
Tari	Northern	M	14	17.65	15.87
Puke	Northern	M	15	11.27	8.94
Karuwai	Northern	F	17	6.64	6.64
Cassidy	Northern	F	14	19.48	16.74
Pukupuku	Northern	F	5	3.76	0.11
Jo	Northern	F	2	0.06	0.02

6.3.2 Overlap

Time series overlap data had similar variances among birds of the same and different genders (Levene's test for homogeneity of variances, Same: $P= 0.06$; Different: $P= 0.07$). Enclosure and gender within the enclosures had the greatest effect on overlap (Table 6.3). There was greater overlap between kiwi of the opposite gender than kiwi of the same gender (Table 6.3; Table 6.4).

Male kiwi overlap was always greater with their respective mate (based on my own knowledge of pairings) than with other birds, but this was not always the case with the female of the pair (Table 6.5). In the southern enclosure some of the females overlapped predominately with Tae mai i te po, the female with the largest home range (according to the Minimum Convex Polygon method, Table 6.2). In the northern enclosure, the only pair that produced an egg, Tuatahi a Nui and Pukupuku, overlapped predominately with each other. All the other birds in the enclosure consistently overlapped with one another and separate home ranges were not apparent.

Table 6.3- Repeated Measures Analysis of Variance of kiwi home range overlap between enclosures (southern and northern), sex (male and female), sex within enclosures. R1 (overlap between same sex or different sex to study bird was calculated separately).

	SS	Degrees of Freedom	MS	F	*P*
Intercept	18461.45	1	18461.45	59.07	**0.00**
Enclosure	1879.80	1	1879.80	6.01	**0.03**
Sex	42.42	1	42.42	0.14	0.72
Enclosure*Sex	39.26	1	39.26	0.13	0.73
Error	3125.52	10	312.55		
R1	856.94	1	856.94	13.02	**0.00**
R1*Enclosure	23.86	1	23.86	0.36	0.56
R1*Sex	185.73	1	185.73	2.82	0.12
R1*Enclosure*Sex	1740.56	1	1740.56	26.44	0.00
Error	658.36	10	65.84	65.84	

Table 6.4- Pattern of overlap between males and females in the Northern and Southern Enclosures at Maungatautari. Means (ha) ± standard errors are given.

	Southern Enclosure	Northern Enclosure
Females overlap Females	26.0 ± 8.5	22.4 ± 9.8
Females overlap Males	14.2 ± 4.8	46.2 ± 5.5
Males overlap Males	0 ± 8.5	33.0 ± 9.8
Males overlap Females	30.5 ± 4.8	35.3 ± 5.5

Table 6.5- Matrix showing percentage overlap of kiwi territories in two enclosures at Maungatautari. Like Greek symbols before kiwi names indicates mating pairs. Not all birds had a mate. F= female, M=male. Bolded numbers are percent overlap between members of a pair. Overlaps greater than 20% highlighted in red.

Symbol	Bird	Sex	Atua	Horokio	Te Rahurahu	Te mai i te po	Parure	Robin	Elmo	Mark	Tuatahi	Tari	Puke	Karuwai	Cassidy	Pukupuku	Jo
X	Atua	F	100	4.7	37.5	51.1	0.9	0.0	9.9	**43.1**	0	0	0	0	0	0	0
Ω	Horokio	F	4.5	100	0.0	0.8	0.0	**50.7**	2.6	0.1	0	0	0	0	0	0	0
Σ	Te Rahurahu	F	45.1	0.0	100	75.4	**39.8**	0.0	6.2	7.4	0	0	0	0	0	0	0
Ʊ	Tae mai i te po	F	41.5	0.7	50.9	100	14.9	0.0	**28.4**	23.1	0	0	0	0	0	0	0
Σ	Parure	M	2.4	0.0	**91.7**	50.9	100	0.0	0.0	0.0	0	0	0	0	0	0	0
Ω	Robin	M	0	**92.1**	0.0	0.0	0.0	100	0.0	0.0	0	0	0	0	0	0	0
Ʊ	Elmo	M	25.1	6.9	13.0	**88.6**	0.0	0.0	100	0.0	0	0	0	0	0	0	0
X	Mark	M	**64.5**	0.2	9.2	42.6	0.0	0.0	0.0	100	0	0	0	0	0	0	0
μ	Tutatahi a Nui	M	0	0	0	0	0	0	0	0	100	22.2	2.0	0.0	10.9	**41.0**	0.0
	Tari	M	0	0	0	0	0	0	0	0	11.3	100	62.7	33.9	83.6	1.2	0.0
	Puke	M	0	0	0	0	0	0	0	0	1.6	98.3	100	49.5	97.9	0.0	0.0
	Karuwai	F	0	0	0	0	0	0	0	0	0.0	90.1	84.1	100	100	0.0	0.0

	Cassidy	F	0	0	0	0	0	0	0	0	5.1	75.7	56.7	34.1	100	0.0	0.3
μ	Pukupuku	F	0	0	0	0	0	0	0	0	**98.3**	5.4	0.0	0.0	0.2	100	0.0
	Jo	F	0	0	0	0	0	0	0	0	0.0	2.7	0.0	0.0	99.7	0.0	100

6.3.3 Consecutive day shelter distances

There was no significant difference in the distances between consecutive daytime kiwi

shelters with reference to sex, enclosure or sex within enclosures (Table 6.6).

Table 6.6- Results of t-tests looking at the differences in mean distances (in metres) of consecutive day shelter locations for males when compared to females in each of the northern and southern enclosures, all males vs. all females, and all birds from northern vs. all birds from southern enclosures. n= sample size.

Enclosure	Sex	n	Mean	SEM	t	*P*
Northern	♂	3	211.67	71.60	-.439	.674
Northern	♀	6	249.17	48.83		
Southern						
	♂	5	201.00	44.45	-.333	.744
Southern	♀	11	223.64	40.70		
Northern &	♀	17	232.65	30.70	-.541	.594
Southern						
Northern &	♂	8	205.00	35.47		
Southern						
Northern	♂/♀	9	236.67	38.20	.404	.690
Southern	♂/♀	16	216.56	30.52		

6.3.4 Shelter distance from water source

The distance of daytime shelters from streams was significantly closer than expected by

chance for all male and female birds in the northern enclosure, but not in the southern

enclosure (Table 6.7). The daytime shelters occupied by male kiwi in the northern

enclosure were significantly closer to water sources than daytime shelters occupied by

female kiwi (Fig. 6.1, Table 6.7). There was an additional small, but constant, boggy area

with no water flowing in the northern enclosure that was not mapped by GIS, this would

have only affected Tuatahi and Pukupuku as it was in their territory. There was no

significant difference between male and female daytime shelters regarding proximity of

shelters to water in the southern enclosure or between all females and all males from both

enclosures (Fig. 6.1). Daytime shelters were also significantly closer to streams than the

average midpoint from ridge to gully in the northern enclosure, but not in the southern

enclosure (Table 6.7). However, individual birds from both sexes and both enclosures

displayed preferences for shelters that were closer to streams than the average midpoint, i.e.

Elmo, Parure, Karuwai, Puke (Table 6.7).
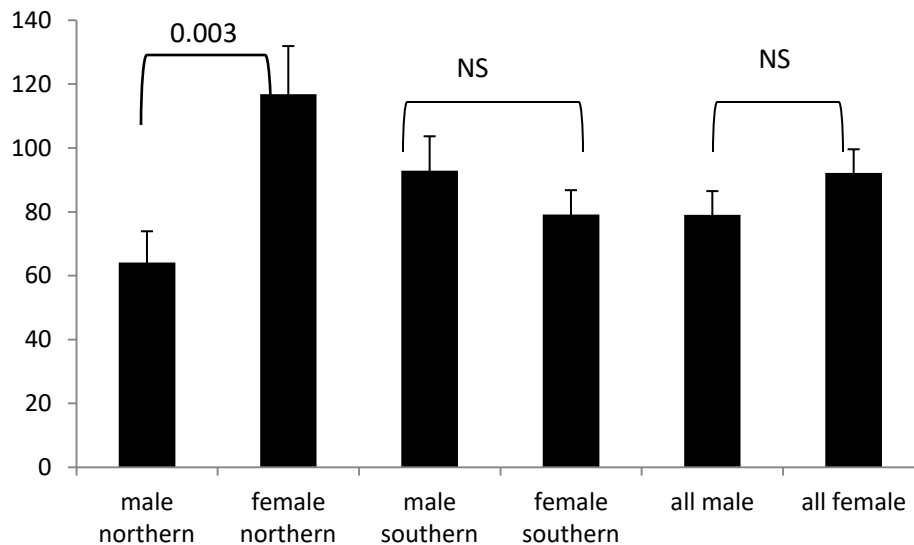
Fig. 6.1 - The results of t-tests comparing the distances of male and female kiwi daytime
shelters to the closest stream in the northern and southern enclosures. Y- axis is the distance
in metres from the stream. NS= Non-significant.

Table 6.7- Distances to stream for all and individual birds versus a mean midpoint calculated from x randomly chosen locations in each of the northern and southern enclosures. SEM = Standard Error of the Mean; t =t-statistic; *P*= p-value.

Sex	Enclosure	Mean distance to streams (m)	SEM	t	*P*
NA	northern	131.36	8.58	---------	----------
♀/♂	northern	86.99	8.99	-2.24	0.03
♀	northern	91.18	16.40	-2.21	0.03
♂	northern	61.00	21.63	-3.23	0.00
♂	northern	87.14	21.58	-2.08	0.05
♂	northern	48.89	6.15	-7.80	0.00
♀	northern	156.1	29.9	0.88	0.39
♀	northern	94.00	28.30	-1.73	0.10
NA	southern	84.38	7.07	--------	---------
♀/♂	southern	85.00	6.39	0.04	0.97
♀	southern	120.00	20.91	2.07	0.47
♂	southern	125.42	18.41	2.52	0.02
♀	southern	84.38	14.61	0.00	1.00
♂	southern	81.67	14.65	-0.19	0.85
♂	southern	45.77	9.74	-3.22	0.00
♂	southern	118.21	29.59	1.40	0.17
♀	southern	67.06	12.51	-1.29	0.21
♀	southern	59.71	12.47	-1.84	0.07

6.4 Discussion

6.4.1 Validity of home range estimation

McLennan et al. (1987) recommended using the complex polygon method for estimating a kiwi range size if the kiwi had been located fewer than 50 times or for less than six months. Potter (1989) claimed that the complex polygon method had a tendency to overestimate range size by including areas that the kiwi may not have ventured. Once the location of daytime shelters and nests were plotted and the complex polygons estimated, I felt confident in my analysis and therefore my conclusions that home range sizes had not been underestimated because night time visuals, and/or calling by the birds, placed them throughout the areas included in the polygons.

6.4.2 Home range size differences between incubating males, non-incubating males, and females

The standout result from this study was the significant difference in home range sizes between mated male and female birds. As only one female bird did not come close to reaching her asymptote, the difference in home range sizes between mated males and females could have been even greater. The range size differences and the variable percentage of overlap between mated pairs dictated that my results be reported for individual birds rather than pairs of birds. Although a number of factors could have contributed to the differences observed in home range sizes between the two enclosures, I suggest mating status to be the primary driver.

 In the northern enclosure, of the three males and four females present, only one pair of birds were known to successfully breed and produce an egg that the male then incubated.

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Two birds, also in the northern enclosure, were classified as being a mated pair when they were observed sheltering together on two different occasions. However, no eggs were ever found. In contrast, in the southern enclosure, every adult kiwi had a mate, and every male took part in incubating one or two clutches. With the average incubating male having significantly smaller home ranges than non-incubating males and females it could be concluded that an incubating male's territory size is the product of his nest fidelity and dedication to sitting on his egg(s). Males did not venture too far from their eggs and the result was a smaller home range size than their mates.

Female kiwi, for the most part, had larger home ranges at Maungatautari regardless of the enclosure they were in and their reproductive status. This contrasts with Potter (1989) who found no difference between male and female range sizes, and Taborsky & Taborsky (1992) who observed that differences in kiwi home range size in Northland depended more on whether the male birds were paired or unpaired. Ziesemann (2011) found that females in the high density population (1 kiwi/ha) on Ponui Island maintained larger home ranges than males regardless of the breeding season. These home ranges were, however, much smaller than home ranges in areas with lower kiwi densities. My study took place during the breeding season in an intermediate density population. My results confirm that presumably gravid females require relatively large home ranges and that this is most likely attributed to the elevated resources needed for egg production. Kiwi males are often the sole incubators (Colbourne, 2002); this allows the females freedom to move further away, possibly in search of resources, and thus increasing the size of their home ranges.

The female kiwi with the smallest territory (6.2 ha) was a non-reproductive bird named Karuwai. She was diagnosed at hatching with a blood disease (Smuts-Kennedy, pers.com) and had a low mean body weight (1729grams) compared to other females in this study (range= 2040-3195 g, n=7). Karuwai was observed in the same shelter, on more than one occasion, with Puke. As this could indicate a pair bond, it is possible that her affliction affected her ability to become gravid and also restricted her range of movement. Ziesemann (2011) predicted that on Ponui Island a female's large home range size was the result of their larger body and high energy demands from egg production. In my study, another non-breeding female in the northern enclosure, Cassidy, had a home range size that resembled those of the breeding females from the southern enclosure (Table 6.2). As she was not known to be breeding there may have been little reason for her to establish such a large home range. However, it is possible that her large range not only resulted from food acquisition, but served to find a potential mate, as she had the most overlap with two of the three males within the enclosure.

Tuatahi a Nui had the smallest home range of the northern enclosure males. His range size, similar to that of southern enclosure males, was likely due to the fact that like the southern enclosure males he incubated an egg. Mark, from the southern enclosure, had a slightly larger home range than the other males which could be the result of his nest abandonment as he was tied to his egg for a shorter period of time than the other incubating males. Mark was also introduced to the enclosure midway through this study when the other kiwi had their ranges well established. Mark's home range may have appeared larger due to a 'settling in' period. I was unable to find any data about how long a 'settling in' period

takes, but within two months of his introduction Mark had paired off with Atua and was incubating an egg.

6.4.3 Territorial overlap

GIS maps showed female kiwi home ranges in the southern enclosure frequently overlapped, but the males in the same enclosure rarely did (Appendix 2 - Figs. A2.Q, A2.R). However, overlap within the northern enclosure occurred with both sexes (Appendix 2 - Figs. A2.G, A2.H). The northern enclosure is almost half the size of the southern enclosure and greater overlap could be a response to higher density. Another reason for greater overlap in the northern enclosure could be because the majority of kiwi were unpaired. Although this is consistent with Taborsky & Taborsky's (1995) finding of unpaired males having greater overlap than paired males, in this instance, an alternative hypothesis is that overlap primarily resulted from dry soil conditions. Wauters et al. (2005) found that red squirrels increased home range size and had greater overlap when there was less food available. Kiwi require softer substrate for probing for soil invertebrates and the northern enclosure has only one permanent stream. The area around this stream would have become increasingly desirable when the upper slopes of the enclosure became too dry in summer. On more than one occasion three kiwi, none of which were paired with each other or related, were found resting near to the stream and within 30 metres of each other. Local records showed long periods with little or no rainfall during this study (Appendix 3 - Table A3.1) and I suggest that the dry conditions most likely prompted kiwi to concentrate around this site creating more home range overlap in the northern enclosure. In the southern enclosure streams could be accessed from multiple points making it unlikely that water access prompted home range overlap there.

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In this study I not only found large overlap between the territories of females and their respective mates, but these female territories extended beyond that of their males. If a male kiwi were trying to entice a female with the resources available in his territory then one might expect that her territory wouldn't need to be larger than his. Assuming that both kiwi of a pair shelter and feed in the same area this suggests that male home range size is not driven by mate acquisition.

6.4.4 Shelter distance from water source

Availability and access to water sources is important to the territory structure of kiwi. Taborsky & Taborsky (1995) found that the majority of kiwi they studied preferred roosting in marshes, and Richardson & Ewen (2016) found that streams were an important factor in territory selection for hihi (*Notiomystis cincta*). Although there were no proper marshes within the Maungatautari enclosures, some kiwi did favour sheltering closer to streams. Males in the northern enclosure had shelters significantly closer to streams than females, but this was not necessarily the case in the southern enclosure (Table 6.7). The southern enclosure, despite being larger in area, had multiple waterways making more water available to more parts of the enclosure. This allowed each pair of southern enclosure birds to have a portion of a stream within their home range. The northern enclosure, however, had only one stream (and a very small boggy area) running through a portion of the enclosure. For all kiwi to have access to this water territorial overlap was essential. The concept of guarding a food source is not new for kiwi (Kotrschal & Taborsky, 2010; Hinsch et. al. 2013) and it is possible that northern enclosure kiwi were adopting this behaviour due to dry conditions in other parts of the enclosure. The water availability in the southern

enclosure may have made it unnecessary for kiwi to reside close to, or 'guard', their water source.

Studies have shown that a male kiwi will often guard resources to attract or retain a mate (Taborsky & Taborsky, 1991; Kotrschal & Taborsky, 2010). As only the northern enclosure male daytime shelters were significantly closer to the stream, I cannot unequivocally state that resource guarding for mate retention is commonly practiced in the Maungatautari population.

6.4.5 Home range sizes versus habitat quality

McLoughton et al. (2000) detailed that home range sizes for brown bears were inversely correlated with habitat quality. Yoon (2014) found that dusky orange-crowned warblers (*Oreothlypis celata*), similarly to brown bears (*Ursus arctos*), were more densely populated in areas with better habitat. Although my study did not assess habitat quality, Watts et al. (2011) showed increases in invertebrate biomass on Maungatautari once vertebrate pests were eradicated. This may indicate the potential for favourable feeding conditions which is a component of habitat quality. As the kiwi in this study are enclosed by a fence we can never know what their home ranges would have been if they had had unlimited area. The birds in the southern enclosure all appear to have their own part of the enclosure. Although there is overlap, it is not complete, which suggests that home range sizes are sufficient. The most successful breeding birds all had constant streams in their territories so it may be that wetter environments allowed for more successful probing and feeding, which led to sufficient weight gains for incubating males and gravid females (Note: I did not have permission to weigh gravid females and incubating males during the course of this study).

6.5 Conclusion

There was significant difference in home range sizes between incubating male and non-incubating male and female kiwi. The home range results for the kiwi at Maungatautari fell within the ranges reported for North Island brown kiwi elsewhere in New Zealand. Overlap amongst birds occurred only between females and unpaired/un-reproductive birds. Water availability, which can affect soil probing and food acquisition, could reduce habitat quality and increase the range overlap between birds. I suggest that reproductive status, coupled with water availability, and therefore habitat quality are primary drivers in determining range location and size for kiwi within the Maungatautari enclosures.

Chapter 7- Shelter selection of North Island brown kiwi (*Apteryx mantelli)* in a pest proof, old growth forest.

7.1 Introduction

Burrows, roosts, dens and shelters are used by a range of vertebrates (Schwarzkopf & Alford, 1996; Grillet et al., 2010; McLennan et al., 1987; Wang et al., 2007; White & Cameron, 2009). Shelters can have varied appearances and can be made of many different materials (Jamieson et al., 2016), but all have the same function: to protect the occupants (potentially including vulnerable offspring) from outside hazards, such as extremes of weather, light for nocturnal animals, or unwanted intruders/predators particularly while they sleep (Tidemann & Flavel, 1987).

Defence against predators drives shelter selection for many species. A long narrow entry can allow an individual to protect its resources or brood (Lantz, 2006; Greger & Hall, 2009; White & Cameron, 2009), while a shelter with multiple entrances can allow for an easy escape if predators invade (pers. obs.). Burrows can also offer a humidity-controlled environment that can reduce water-loss and buffer against high temperatures, as reported in many desert-dwelling amphibians and reptiles (Schwarzkopf & Alford, 1996; Grillet et al., 2010). In cold climates shelters can also alleviate the effects of extreme cold and high winds (Wang et al., 2007).

New Zealand's five kiwi species are examples of animals that can use many different types of shelters. North Island brown kiwi (*Apteryx mantelli,* henceforth ' kiwi'), for example, shelter in excavated burrows, tall grasses, bracken and shrubs, natural cavities and fallen

vegetation, and can be found among roots (where cavities occur), under fallen trees, or inside hollow logs and windrows of coarse woody debris (Colbourne & Kleinpaste, 1983; McLennan et al., 1987; Miles et al., 1997; Jamieson et al., 2016; pers. obs.). Kiwi habitat and shelter selection have been studied in pine plantations, regenerating forest, and relatively large blocks of conservation land including National Parks (McLennan et al., 1987; Potter, 1989; Taborsky & Taborsky, 1995; Miles at al., 1997); all of which contain kiwi predators, e.g. dogs and mustelids that contribute to their decline.

The kiwi is listed as an 'At Risk' species in serious decline (Robertson et al, 2016). Although kiwi continue to be a prominent New Zealand icon, knowledge of their behaviour is still limited due to their nocturnal lifestyle. A number of private, community and government conservation efforts are underway to aid their survival (Holzapfel et al., 2008; Germano et al., ND); poisoning and trapping efforts aim to create areas with reduced or zero numbers of pests both on the mainland and on offshore islands.

More recently, areas enclosed with pest proof fencing have been constructed and any mammalian pests inside have been eradicated (Burns et al., 2012). This provides not only a pest free area for threatened species, but it limits reinvasion once pest eradication has occurred. Management techniques for *Apteryx* spp. inside pest-proof fenced enclosures are relatively new and no standards exist detailing how large these areas should be or the types of habitat they should include to maintain healthy kiwi populations. Many of the current fenced predator-free reserves contain only small areas of regenerating forest (Burns et al., 2012). The few reserves with old growth forest may provide a wider range of shelter options both above and below ground due to the accumulation of coarse woody debris and

litter. Kiwi can live in a variety of habitats, but their specific habitat choices reported in previous studies (McLennan et al., 1987; Potter, 1989; Taborsky & Taborsky, 1995; Miles et al., 1997; Jamieson et al., 2016) are likely shaped by the availability and relative abundance of options and may not reflect any 'ideal' or 'optimum'. The complexity of an old growth forest may provide kiwi with increased shelter options and allow them to exhibit a wider range of behaviours.

The aim of this study was to identify the range of shelter types used by kiwi at Maungatautari; an enclosed area of native, old growth forest free from predators (Chapter 2). Preferential shelter usage can serve as a model for assessing existing habitat quality at new potential reintroduction sites, and designing kiwi habitat to restore elsewhere.

7.2 Methods

For information about study area and study population see Chapter 2. For acquiring information on daytime shelter types, 15 kiwi were observed over approximately ten months (Table 7.1).

Table 7.1- Details of the kiwi within the northern and southern enclosures at Maungatautari, and the periods over which they were observed to determine shelter choice. The dates vary across birds due to variable dates of introduction and the loss or failure of transmitters. Incubating males are noted, as this has a bearing on shelter usage.

Enclosure	Name of Bird	Sex	Observation Period	Comments
Northern	Karuwai	♀	15 Jun 08-26 Feb 09	
	Pukupuku	♀	5 Feb 09-26 Feb 09	Found towards end of study
	Jo	♀	8 Sept 08- 5 Nov 08	Introduced later in study and transmitter failed
	Cassidy	♀	3 Jul 08-28 Jan 09	Transmitter dropped
	Puke	♂	14 Jul 08-7 Feb 09	Transmitter failed
	Tari	♂	14 Jul 08-26 Feb 09	
	Tuatahi a Nui	♂	14 Jul 08-26 Feb 09	Incubated a 'dud' egg at start of study
Southern	Atua	♀	10 Jun 08-3 Nov 08	Transmitter dropped
	Horokio	♀	12 Jun 08-27 Jul 09	
	Tae mai i te po	♀	12 Jun 08-28 Jan 09	Transmitter dropped
	Te Rahurahu	♀	10 Jul 08-27 Feb 09	
	Elmo	♂	13 Jul 08-1 Mar 09	Successfully incubated 1 egg during this study
	Mark	♂	1 Sept 08-1 Mar 09	Incubated and abandoned 1 'dud' egg during this study
	Parure	♂	13 Jun 08-1 Mar 09	2 unsuccessful clutches were incubated
	Robin	♂	13 Jul 08-1 Mar 09	2 successful clutches were incubated

The place where a kiwi sleeps during the daytime has been given several names. Colbourne & Kleinpaste (1983) chose to use the term burrow, while McLennan et al. (1987) used den and roost. As burrow is defined as "a hole or excavation in the ground made by an animal"

(www.Merriam-Webster.com; accessed December 2017), I chose not to use this term as kiwi could be above ground or not in an excavated site. A roost is defined as "a support on which birds rest" (www.Merriam-Webster.com; accessed December 2017). This also seemed inappropriate as kiwi in this study did not use supports where they rested. A den is defined as "the lair of a wild usually predatory animal" (www.Merriam-Webster.com; accessed December 2017). Kiwi would not best be described as a predatory bird nor does the term describe that they are, in fact, resting. In this study I use the term shelter to define where a kiwi stays during the day.

Radio telemetry was used to locate kiwi in their daytime shelters in both the northern and southern enclosures at Maungatautari on multiple occasions between 3 July 2008 and 1 March 2009. I also included in the data observations taken during one week in May 2009 when kiwi were caught for their regular health check. I attempted to locate kiwi entry holes and describe shelter types with little or no disturbance to the kiwi, however, shelter types were also recorded when kiwi were caught and handled for health checks. Shelters were located and the date of use and shelter type were recorded as often as possible for the 15 different adult kiwi (males, n = 7; females, n = 8; Table 7.1). When a male kiwi transmitter was signalling incubation, I kept at least five meters minimum distance from the shelter, as mandated by the MEIT Science & Research Committee, to prevent disturbance and possible abandonment of the nest. As incubation implied the exclusive use of one shelter/nest, no data were lost from not continuing to record kiwi while they were nesting.

7.2.1 Detailed shelter type classification

Shelter types encountered were described. These descriptions were then organized into separate detailed and broad scale classifications based on the predominant shelter material and location. The detailed shelter classification types were:

Exploited Root System - Existing holes underground resulting from rotted roots that may have been further modified by kiwi for shelter usage (Fig. 7.1).

Downed Mass - Complex fallen debris consisting of trees, epiphytes, supplejack, and other lianes.

Hollow Log – A downed tree with a cavity inside that a kiwi could shelter in.

Leaf Litter Mound - Composed of built up leaf litter, but also included dead tree-

fern fronds that had formed a 'skirt' around the base of a tree fern trunk.

Burrow - A purposely dug underground hole (Fig. 7.2).

Fallen Log - A cavity under a downed tree that allowed a kiwi to shelter (Fig. 7.3).

Windrow - Trees and debris that had been cut down during the construction of the enclosure fence. These usually formed a long 'highway' of debris, but was classified separately from a downed mass because of the adjacent corridor resulting from the fence line that provided easy access around the perimeter of the enclosure (Fig. 7.4).

Mamaku Frond Clump - Fallen fronds of *Cyathea medullaris* (mamaku) that had amassed in homogenous stands of this species (Fig. 7.5).

Surface Vegetation - Live vegetation on the ground, e.g. ferns, sedge or grass tussocks.

Drainage Pipe - Wooden and plastic piping that was installed throughout the enclosures to control surface runoff and flooding around tracks and the fences.

Hole used by kiwi

Fig. 7.1- Exploited Root System

Fig. 7.2- Burrow

Kiwi's hole on the backside of the log

Fig. 7.3- Fallen log

Open corridor on inside of fence.

Decomposing windrow mound

Fig. 7.4- Windrow

Fig. 7.5- Mamaku Frond Clump

7.2.2 Broad shelter type classification

Dead Vegetation Mass - Included the shelter types with high levels of decomposing matter, i.e. mamaku frond clump, windrow, fallen logs, leaf litter mound, hollow log, and downed mass.

Live Surface Vegetation - Live vegetation on the surface of the ground

Underground Cavities - Included burrows and exploited root systems.

Un-natural Objects - Objects, not naturally in the environment, such as a treated wooden drainage pipe.

7.2.3 Statistical analysis

Shelter type usage was reported as a proportion of total observations for each bird. Originally classified at a detailed level, these shelters were later grouped into the broader classification to improve statistical robustness. I hypothesised that if a kiwi shelter choice was random an equal proportion of each shelter type would be selected (assuming that all shelter types were equally available for selection). Preferences for different shelter types (using the detailed and broad classifications separately) used by individual male and female kiwi were compared between seasons, and between northern and southern enclosures using chi-squared analysis. The top two preferred broad classifications were compared using a t-test. Chi-Square tests compared preferred broad shelter classifications for gender, enclosure and gender within the enclosures.

7.3 Results

7.3.1 Shelter usage

Over 10 months, 217 kiwi shelters were observed: 94 in the northern enclosure and 123 in the southern enclosure. Using the broad shelter type classification, 74.2 ± 3.2% of shelters were in Dead Vegetation Mass, 24.9 ± 11.3% were in Underground Cavities, 0.44 ± 0.44% were in Live Surface Vegetation and 0.33 ± 0.33% were in Un-Natural Objects. With the exception of one bird, Tae mai i te po, all individual kiwi used Dead Vegetation Mass proportionally more than Underground Cavities (Fig. 7.6).

Using the detailed classification, shelter usage across all kiwi was: 37.7 ± 5.4% for Windrows, 24.9 ± 3.0% for Exploited Root Systems, 14.1 ± 2.9% for Downed Logs, 12.3 ±

2.8% for Downed Masses, 4.6 ± 1.5% for Leaf Litter Mounds, 2.6 ± 1.0% for Burrows and 2.5 ± 1.3% for Mamaku Frond Clumps. Hollow logs, Live Surface Vegetation and Drainage Pipes all had less than 1% usage.

As individuals, Horokio (♀), Robin (♂) and Elmo (♂) in the southern enclosure, and Cassidy (♀) and Tuatahi (♂) in the northern enclosure, stood out as having strong preferences for Windrows, whereas Tae mai (♀) in the southern enclosure was more often found in Exploited Root Systems. Only male kiwi were ever found in burrows (Appendix 4- Table A4.1).
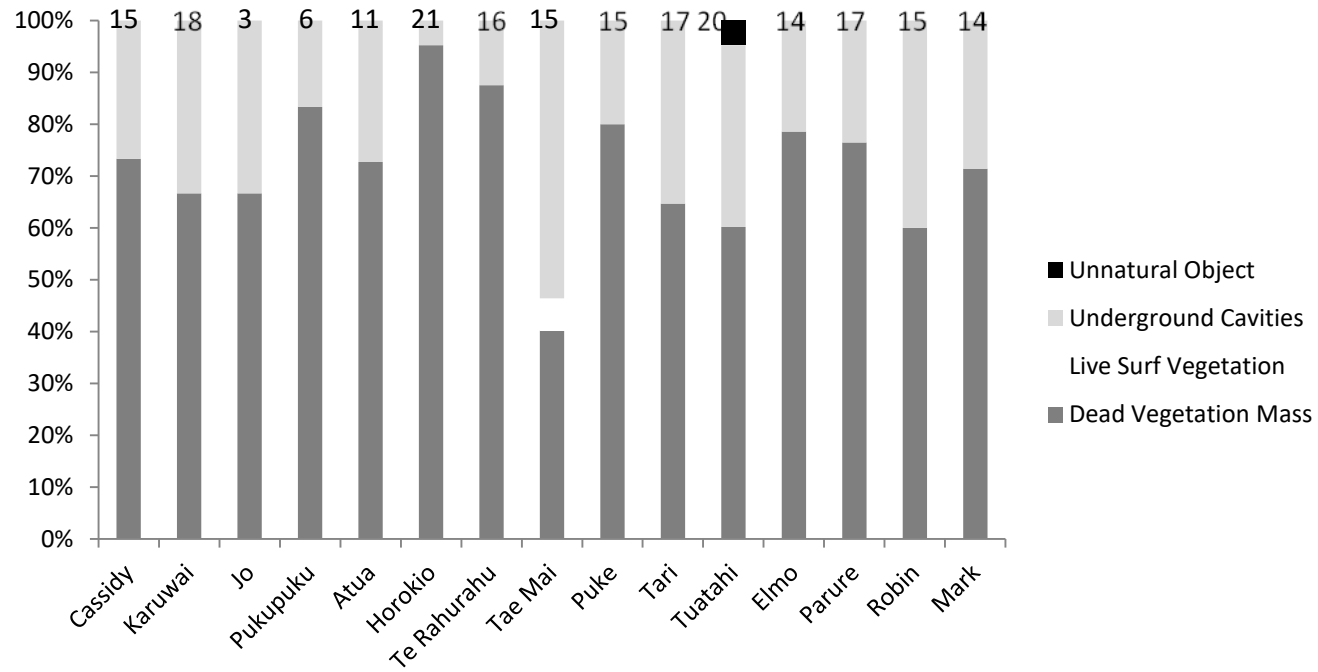
Fig. 7.6- Individual kiwi shelter use (as a percentage) at a broad classification level. Number above column equals the total number of shelters located for that kiwi.

All kiwi showed a significant preference for 'Dead Vegetation Mass' over 'Underground Cavities' (t= 10.9, n=15, $P < 0.001$).

As the instances of kiwi found sheltering in 'Live Surface Vegetation' and 'Un-Natural Objects' equalled one per classification type, Chi-Square tests compared only 'Dead Vegetation Mass' and 'Underground Cavities' for gender, enclosure and gender within the enclosures. No significant differences were found in type of daytime shelter used between males and females (χ^2= 0.317; n = 205; P =0.574), northern and southern enclosures (χ^2= 1.237; n = 205; P =0.266), or males and females in each of the northern enclosure (χ^2=0.036; n= 88; P= 0.851) and southern enclosures (χ^2=0.230; n= 117; P= 0.631).

Dead Vegetation Mass was used for sheltering substantially more often than Underground Cavities, even on a seasonal basis (Table 7.2). Throughout the seasons neither males nor females changed their proportional use of Dead Vegetation Matter or Underground Cavities (♂ χ^2=0.121; n= 105; P=0.94; ♀ χ^2=1.475; n=100; P=0.478). There was also little difference in seasonal shelter usage by kiwi in the northern compared with the southern enclosure (Northern enclosure χ^2=0.325; n= 88; P=0.85; Southern enclosure χ^2=1.609; n=117; P=0.447). Although shelter usage did not appear to be seasonal at a broad classification level (Table 7.2), on a detailed level Windrows stood out as being preferred during summer months (Appendix 4-Table A4.2).

Table 7.2 - Mean seasonal proportional shelter usage by kiwi. Note: Live Surface Vegetation and Un-natural Object classifications not shown due to low usage.

Season	Dead Vegetation Mass	Underground Cavities
Winter	0.691	0.294
Spring	0.726	0.274
Summer	0.737	0.263
Autumn	0.800	0.200

7.3.2 Nests

Burrows were only used by male kiwi and were always nests. Nests, however, were not always burrows. Exploited Root Systems were used twice and Leaf Litter Mounds were used once.

7.3.3 Shelter reuse

With the exception of nests, 15 individual kiwi re-used shelters only four out of 209 occasions. The birds that were involved in re-using shelters were considered breeding pairs. In two of the incidents Puke and Karuwai were found together in two different shelters. In the other two instances Elmo was found in a hole that he had previously shared with his mate Tae mai. On many occasions kiwi were found in areas they had used before but almost never in the same shelter. For example, Tuatahi a Nui was often located near the front of the D-line, but the entry hole to his shelter was never the same. It is possible that the shelter was connected to his other shelters by a network of tunnels making it, functionally, the same shelter.

7.4 Discussion

7.4.1 Shelter usage

'Dead Vegetation Mass' as a broad shelter type was used nearly three times more often than 'Underground Cavities' by kiwi at Maungatautari. Their use was consistent in the Maungatautari northern and southern enclosures, regardless of season or the gender of the kiwi. I did not attempt to quantify the availability of these shelter types because it was not always obvious what could be used as a shelter. Meagre or elaborate, visible or underground, I was regularly surprised at the broad range of shelters I found kiwi resting in. Kiwi may have used Dead Vegetation Matter more often to shelter in because it was more visible to them. The existence of underground cavities would be difficult to quantify because you cannot necessarily tell what's beneath your feet and I assume neither can the kiwi. I pulled kiwi out of holes underground that were nearly my entire body length long. Before this study, I did not realise the degree of 3-dimensionality beneath the surface of an old growth forest, but now I know that at Maungatautari it is extensive.

Deep underground refuges are said to have stable environmental conditions that not only relieve the occupant during hot summers and drought, but conserves heat in the winter (Grillet, 2010; McLennan, 1987). These benefits may be the reason why Exploited Root Systems, usually the deepest and most complex of the shelter types, had consistent usage throughout the seasons, but their inconspicuousness may have been why they were not, overall, the most used shelter type. As kiwi most likely see and sense the forest differently than a human, I can't be sure of their choices.

The slight decrease in use of Dead Vegetation Matter and the slight increase in use of Underground Cavities during winter months could reflect the kiwis' efforts at "conserving heat in the winter"(McLennan, 1987). Walsberg (1986) showed that shelters with an almost complete overhead cover were able to significantly reduce wind velocity and hold a higher temperature than outside. I assume that an underground cavity would be able to minimise temperature and humidity fluctuations even more and aid kiwi with their thermoregulation (Tidemann & Flavel, 1987; Jamieson et al., 2016; I. Castro pers. com.).

Maungatautari is primary old growth forest (Burns & Smale, 2002), with lots of coarse woody debris (Richardson et al., 2009). The southern enclosure alone has 2500 m of nearly continuous decomposing windrow (pers. obs.). This combined with the fact that on average 1.5% of trees greater than 10 cm die every year in New Zealand forests (Bellingham et al., 1999) indicates that there is an abundance of dead vegetation and coarse woody debris on Maungatautari. This may be favoured by kiwi for at least two reasons:

1. The decomposition of vegetation means it will contain a large number of detritivores (MacNally & Horrocks, 2007). Kiwi, therefore, may favour 'Dead Vegetation Matter' as a shelter type because it also provides a food source while they are sheltering.
2. The high quantity of downed vegetation provides ample areas for kiwi to shelter in without them needing to expend effort to create them, so kiwi may be using this shelter type because it is so readily available at low cost.

The frequency of Underground Cavities is more difficult to quantify. During the fieldwork for this study I was often surprised how deep a kiwi was in their shelter. For

example, I caught Tae mai i te po three metres in from her entry hole. On another occasion I caught Mark three metres in and one and a half metres down from his entry hole. The multi-layered forest structure seems to have resulted in an impressive network of tunnels but it is impossible to definitively conclude that Dead Vegetation Matter was used more than Underground Cavities relative to the opportunities each presented as neither could be quantified with accuracy.

Windrows, which are technically above-ground, could be quite convoluted. Comprising an estimated 1% of the area within the reserve, kiwi favoured the windrow during all months except winter (Appendix 7.2). Windrows were extensive and virtually continuous in the enclosures during this study. Adjacent to the fence line, the narrow clearing that runs parallel to the windrow provides a 'highway' for the kiwi, which they were frequently observed running along (T. Connolly, pers. com.). This availability of a highway for quick movement adjacent to shelter may have made the windrow an attractive place to use. Twelve of the 15 study birds were regularly seen near the fence line. It is possible they were looking for an opening in the fence in hopes of expanding their territory or they were 'boundary pacing'; a behaviour often seen in captive-held animals (Mallapur & Chellam, 2002). The windrow is also one of the shelter types comprised of decomposing vegetation which may be used preferentially because of the invertebrates potentially present and the heat generated by the decomposing matter. Although a clear visual picture of the internal structure of the windrow is not available, I deemed it nearly continuous because kiwi regularly evaded capture by running long distances inside of it (pers. obs. using radio telemetry). While they exist, such lengthy tunnels could provide good air circulation (despite decomposition compacting the dead

vegetation around the 'tunnels') making the windrow the most suitable shelter for warmer months and less so for winter months.

7.4.2 Shelter reuse

Based on past evidence of the multitude of places kiwi have been found resting during the daytime, Maungatautari has a seemingly unlimited number of shelter sites, which could be why they are so infrequently re-used. Of the four occasions where shelter sites were re-used, two occasions were by the same pair of birds. Another occasion was when a member of a different pair of birds sheltered in a place where he had been previously with his mate. It seems probable that during the breeding season kiwi breeding pairs return to particular shelters to 'meet up' with their mate and increase bonding time.

Both the single use and recycling of refuges have been documented in other studies. In Tongariro, as in my study, kiwi rarely used a shelter more than once (Miles et al., 1997). In the Hawke's Bay one pair of kiwi used 32 shelters in 23 days and another two shelters were recorded being re-used as many as five times (McLennan et al., 1987). Potter (1989) found that the kiwi in his Paerata study re-used shelter sites far more than the Hawke's Bay birds and that there was actually competition for premium shelters. Potter also recorded the refuge sites of one male kiwi 53 times; only 34 different shelters were used during this period, one of which was re-used seven times. As kiwi territories at Paerata and Hawke's Bay were of similar size, the higher rate of shelter re-use at Paerata was unlikely due to the lack of sites, but perhaps rather their level of quality as there was competition for particular shelters. However, at Tongariro, territory sizes were much larger than at Paerata, Hawke's Bay or Maungatautari and therefore it is possible

that infrequent shelter re-use was due to greater availability of shelter options within a larger area.

Shelters may also be used as a social tool. In areas with higher densities of brown kiwi such as Ponui Island, shelter re-use is more common because birds may seek each other out, just like pairs do in most places during the breeding season (I. Castro, pers. com.). Multiple birds have also been known to shelter socially in this high density population (Ziesemann, 2011).

The seemingly unlimited number of shelter options for kiwi within the Maungatautari enclosures would make re-using them unnecessary. The range of shelters may be more pronounced because the enclosures are pest-free. Although not all the kiwi in this study may have had experience in the wild, while at Maungatautari, they lacked the pressure to seek out shelters that would offer protection or provide an easy escape from predators. The kiwi, being free to 'duck in' anywhere at the end of the night, therefore have a greater selection of shelters to choose from. Predator presence at the other study sites could be reducing the number of suitable shelters.

7.4.3 Burrow use

My description of a burrow stipulates that the kiwi dug it themselves. With so many potential shelter sites in Maungatautari there would be little need to expend the energy required to make a shelter for one day. This expense, however, may be justified for something as significant as a nest. Kiwi appeared to have dug out their own nests in five of eight instances. Two Exploited Root Systems and a Leaf Litter Mound were sufficient to house kiwi eggs, although visible modifications to these sites were still

made. Only the males on Maungatautari used burrows and it was always associated with a nest. In Hawke's Bay both males and females used burrows although the males used them significantly more (McLennan et al., 1987). In areas with fewer shelter options it's possible that more energy is devoted to shelter building. Burrows were the most used shelter type in the Hawke's Bay, however, it was indicated that den sites were readily availability.

7.4.4 Nest reuse

Nests were never re-used at Maungatautari. Re-using of nests has been documented previously (McLennan, 1988; Potter, 1989; Colbourne, 2002), but re-use was never to the extent of that on Ponui Island. The high population density of kiwi on Ponui means all resources are competed for (Ziesemann et al., 2011; Cunningham et al., 2007). In one Ponui study, 68% of incubating males used a previously-used nest. It was also recorded that kiwi had re-used nests for three consecutive breeding seasons and that successful clutches were usually in nests that had been re-used (Ziesemann et al., 2011). Daytime shelters are re-used on Ponui Island as well (I. Castro, pers. com.). Maungatautari's 2008 breeding season yielded three successful clutches (Table 7.1) all of which were in new nests that were never then re-used that year.

Nest re-use could, again, be the result of availability. In the southern enclosure at Maungatautari, I found four sites in Elmo's territory that looked to be the attempted excavation of burrows. Although I don't know why he chose not to complete any of these, it did seem that he had ample opportunities for digging. It has never been documented whether it is the male or female that digs the nest, but as the attempted burrows were all in Elmo's core area; this instance indicated to me that it was the male

giving the female a number of options of where to lay her egg(s). However, in Chapter 3 I have video footage of a female digging in a shelter. Despite this, I hypothesise that the energetic expense of carrying such a large egg is enough to discourage nest excavation by females. I. Castro (pers. com.) has stated that females usually choose their nests before egg laying, however, there is nothing in the literature to confirm how long before egg laying this occurs.

7.4.5 Surface vegetation

Out of 217 observations, only once was a kiwi found in live surface vegetation. Regarding the classification of surface vegetation with the studies highlighted below, it is unclear if the vegetation was alive or dead, but the author's descriptions suggest it was alive. This being the case, my findings contrast with both Colbourne & Kleinpaste (1983) and Potter (1989) whose Northland studies recorded a preference for surface vegetation (95% and 45.65%). It also contrasts with kiwi in Tongariro Forest that sheltered in surface vegetation primarily during summer months (Miles et al., 1997). McLennan et al. (1987) recorded, in their two Hawke's Bay study sites, kiwi sheltering in surface vegetation 27% and 29% of the time. There was no preference by Ponui kiwi for surface vegetation which is attributed to the lack of protection it provides from the elements (Jamieson et al., 2016). Lack of preference for surface vegetation by Maungatautari kiwi can probably be explained by its low availability. Bracken (*Pteridium esculentum*) was available in the Hawke's Bay, thick undergrowth was described in Paerata, and toetoe (*Austroderia toetoe*) grew in Tongariro. Maungatautari has no history of burning and only some selective logging around the edges of the forest. *Austroderia* spp, or tussocks, are present, but in low numbers. With underground cavities and refuges associated with dead vegetation matter being readily available, plus

the probable added benefit of thermo-insulation from temperature variations in these shelter types, surface vegetation seems a less likely choice for a daytime shelter on Maungatautari. If buffering against the cold is a primary concern for kiwi then it appears logical that Northland birds favour a less buffered refuge. Tongariro birds favouring shelter in surface vegetation during summer months also is logical. These are times of year and places that low temperatures are less of a concern. Kiwi in areas where predators exist may also be favouring surface vegetation as it allows for easy escape should a ferret or cat pay a visit.

7.4.6 Shelter defence

In this study, all kiwi nests had a single entrance as opposed to their daytime shelters, which tended to have multiple entrances. White & Cameron (2009) stated that a single entrance burrow allowed for better defence. Jolly (1985) found that weka (*Gallirallus australis*) ate 66% of the kiwi eggs laid in his study population. Although the disruption of nests by weka is still taking place in other populations, the co-existence of weka and kiwi for millions of years (Fleming, 1962; McLennan, 1988) may still be influencing kiwi shelter design. Weka are not currently present on Maungatautari, but nests appear to be constructed with defence in mind, i.e. a single entrance, with a moderate to long entry way.

The advantage behind a preference for multi-entranced daytime shelters was frequently exhibited when kiwi were caught for their health checks. A kiwi would often 'slip out the back' when the predator/researcher would enter from the front. This is not to say that kiwi were never found in daytime shelters with single entrances, just less frequently.

7.5 Conclusions

Kiwi seem to use whatever shelter types are present. Maungatautari's kiwi utilised Dead Vegetation Matter the most, but while there is a profusion of this shelter type, underground cavities, although not quantified, also seem abundant. I would conclude that the ease of access around the fence line and the 'boundary pacing' behaviour contributes to the windrow being a favoured shelter type on a detailed level. This, in conjunction with the great number of refuge possibilities made available by Dead Vegetation Matter predisposes it to be preferred at the broad classification level.

The infrequent reusing of shelters can also be attributed to abundance of availability. The Maungatautari kiwi already have relatively small territory sizes (Chapter 6) and yet they have little apparent need to recycle shelters. If kiwi densities increased we might expect the highest quality shelters to be re-used by the same or other kiwi. As refuge possibilities within this old growth forest appear endless, kiwi populations would have to increase dramatically before shelters became a commodity. For future designs of kiwi enclosures it seems a complex forest structure with ample coarse woody debris is vital to ensure sufficient suitable shelter sites. Future research should investigate the extent of thermal buffering afforded by different shelter types so that we may understand which is most advantageous under harsh environmental conditions.

**Chapter 8- Conclusions and suggestions for future study of kiwi (*Apteryx* spp*.).*

8.1 Achievement of thesis aims

North Island brown kiwi (*Apteryx mantelli,* henceforth' kiwi') are flightless, nocturnal, usually solitary, and secretive birds (Heather & Robertson, 2015). Their long isolation from mammalian predators, but evolution with avian predators, has resulted in a range of behaviours ill-adapted for defence against the mammalian pests that now threaten them (Gibbs, 2006). The surge in restoration projects designed to reverse the decline of current populations has developed with little knowledge of how kiwi interact with their environments and socialise with other kiwi. It is therefore necessary to understand how kiwi satisfy their basic needs of gaining food, shelter, and reproduction to better manage population recovery. In this thesis, I endeavoured to obtain a clearer picture of an adult kiwi life within a pest-proof fenced conservation area focusing around the breeding season. Although not all of the study aims were met fully due to the difficulties of working with a wild, nocturnal, and discreet bird, nevertheless valuable data and observations were collected that shed light on the kiwi's secretive nature and how members of a population interact in a limited space.

The following are the original study aims and some of the important outcomes of this research.

8.1.1 Establish and decipher activity patterns over 24-hours from activity transmitter data

Ascertaining when and how much time kiwi are active/inactive helps create a general picture of their day to day activities. Male (Chapter 3) and female (Chapter 4) activity patterns were recorded by different methods and therefore unfortunately could not be

directly compared statistically. The total activity per day of incubating versus non-incubating male birds was significantly different with incubating males averaging only 209 minutes compared to 604 minutes per day in non-incubating males. Although there were not enough replicates to be conclusive, if eggs were fertile, then the males who were more dedicated to sitting on their eggs (i.e., recorded less activity indicating movement away off eggs) had successful clutches. Of the non-incubating males, total time spent active decreased as night length decreased, but the proportional activity usually increased, i.e. the shorter the nights, the more of that time kiwi spent active in them. The longest nights occur during winter which is usually the wettest of the seasons. Wetter conditions make for easier soil probing so it may be that kiwi are able to fill their nutritional needs more efficiently. Winter is also the start of the breeding season so it is possible that the remainder of the night is used for activities relating to reproduction. On the short, drier summer nights a male kiwi needs the full night to fill all of its nutritional and other requirements.

Female kiwi, however, did not behave similarly to the males (Chapter 4). The proportion of active time per night was not correlated with night length. Where male total activity decreased as night length decreased, female kiwi continued to be active for greater than the night length. If the duration of night time activity is related to fulfilling nutritional requirements then the high nutritional demands of egg production could explain higher activity. Even if a female kiwi does not have an egg she may be attempting to keep her condition high in preparation for the next egg. Females are also usually the bigger bird of the sexes so just maintaining condition would require more effort. As I have found no published data about how active kiwi are at other sites, I cannot compare the level of activity at Maungatautari and know if it is lesser or greater.

If this information was available it could indicate the level of quality of the Maungatautari habitat.

I was not able to determine whether male activity was only at night or if they were also active during the day, but female kiwi transmitters indicated that females were being active during the day as well as night and sometimes for extended periods. Large signal strength fluctuations during the daytime even suggested that kiwi were moving around outside of their shelters and settling in a different shelter at the end of this activity. Although there was some activity in the pre-dusk hour, there was a surprising amount of activity post-dawn when, at the end of the night, you might assume kiwi would be back in a shelter. As feeding conditions at pre-dusk are unknown to the kiwi that have yet to emerge from their shelter, it is possible that feeding is continuing into post dawn if the nutritional requirements have not been fulfilled.

Rainfall had an effect on pre and post-dawn activity with significant increases in activity in the days following a rain event. There was also a trend toward increased daytime activity after rain. Kiwi may be taking advantage of the softer soils resulting from rainfall and feeding while the conditions are favourable (Colbourne & Kleinpaste, 1983).

8.1.2 Observe diurnal and nocturnal behaviours of kiwi within the pest free environment of Maungatautari using video cameras.

Little nocturnal behaviour was captured outside of shelters by filming during the course of this study due to the density of the understory within the Maungatautari enclosures and no analysis was possible. However, I achieved more success filming kiwi inside

their shelters during the daytime (Chapter 5). Diurnal behaviour consisted of more than just sleep. Scratching, stretching, preening, excavation, defecation, yawning, feeding and sniffing the air were all behaviours caught on camera (https://www.youtube.com/watch?v=TJlHLHQDGs8). Although sleep was the primary activity, the amount of sleep varied, and was less when a mate was also present in the shelter. In some instances when a mate was present kiwi were active more than they were inactive. This study is, to my knowledge, the first time mate preening has ever been recorded for kiwi. This behaviour was exhibited by all paired birds filmed and supports the importance of pair bonding in this species. Mate preening, or allopreening, has been observed in many animal species, including birds. Although it has been reported that this behaviour helps to maintain pair bonds and may benefit birds hygienically, Cox (2012) suggests there may be other functions that are not well understood. I made observations of male kiwi allopreening the female cloaca region. Although this may have been for hygienic reasons, further research on allopreening in kiwi could uncover alternative functions such as stimulation prior to mating.

8.1.3 Establish the size and distribution of kiwi territories within fenced areas

Kiwi distribution and area of home ranges within the Maungatautari enclosures were influenced by gender and reproductive status (Chapter 6). Coupled birds ranged in distinct areas of the enclosures whereas single birds were not anchored to their own specific area. Mated female kiwi regularly overlapped their home range with each other whereas the majority of mated males only overlapped their territories with their mate. Despite kiwi overlapping their territories with their respective mate, their overlap was not 100%. Both male and female unmated kiwi home ranges overlapped considerably with each other. Minimum Convex Polygons estimated the home range size of: southern

enclosure males = 8.22ha ± 1.24ha; southern enclosure females = 17.28ha ± 1.41ha; northern enclosure males = 11.77ha ± 2.51ha and northern enclosure females = 12.32 ± 6.08ha. These home range sizes suggest a moderately dense population compared to estimates elsewhere (e.g. 5ha per pair in Northland (Potter, 1990) to 19 – 48ha per bird at Lake Waikaremoana (McLennan et al., 1987), with more dense populations existing elsewhere, e.g., 3ha per bird on Ponui Island (Ziesemann, 2011)). Proximity to watercourses is likely to be an important component of home ranges as it ensures softer soils for bill probing/ground invertebrate capture particularly during dry summer months.

8.1.4 Establish shelter preferences of kiwi in fenced areas.

The two major broad categories of shelter types kiwi used were Dead Vegetation Mass (71.9% of shelters observed) and Underground Cavities (27.2%) (Chapter 7). At a more detailed classification level, the most preferred shelter types were Windrows (37.5% ± 5.5%), Exploited Root Systems (24.9% ± 3%), Downed Logs (14.1% ± 5.5%), and Downed Masses (12.3% ± 2.8%) . The windrow (piles of dead wood associated with the clearance necessary for fence construction and occurring as a linear strip adjacent to the fence) was the favourite shelter type most likely because of the easy access for movement around the enclosure provided by the adjacent fence line gap, the continuous undercover corridor of downed coarse woody debris, the availability of multiple exits for a quick get-away, and the decomposing vegetation and therefore invertebrate life which would provide a food source while sheltering. Although the total number of shelter possibilities was not quantified, the abundance of quality shelters available to kiwi in the old-growth forest at Maungatautari made re-using them on more than one occasion unnecessary. Kiwi used new shelters on each observed night except when

nesting. No competition for shelters was evident either. An old growth forest or any similar area with an abundance of coarse woody debris and macrolitter (e.g. dead tree fern fronds) should provide a multitude of shelter options for kiwi.

8.2 Other Outcomes

Although the data were not presented in this thesis, regular health checks were carried out on the study kiwi and at no time was there any concern that the kiwi were not doing well. Condition, weight and the lack of dermal parasites all indicated that the kiwi were healthy during the course of this study. The size of the enclosures does not seem to have hindered the kiwi from forming pair bonds, attempting and in some cases achieving reproduction, and maintaining weight and condition. These observations confirm that Maungatautari is achieving positive outcomes for the translocated kiwi population there. The size of the enclosures and stocking rates do not seem to be limiting and the quality of habitat is presumably sufficient for kiwi needs.

Other observations were made on the kiwi and although they may not be scientific, they are behavioural and indicate that many of these kiwi had their own personalities. Most noticeable when trying to catch the kiwi, individuals responded to me in different ways. For example: Mark never attempted to flee when being captured. I always had to catch him with a gloved hand because he would stand his ground and fight me until he was caught. In contrast, Elmo was out of the shelter when I was still 10 metres away and would lead me on an exhausting 'wild goose chase' to which, I might add, he almost always eluded me. Te Rahurahu always dropped a pile of feathers when caught and Karuwai usually defecated on me. All of these behaviours were helpful to know when I

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was dealing with the birds. They also confirm that behaviour is unique, variable and cannot be predicted for all kiwi.

8.3 Future Research

Similar studies in progressively smaller sized areas would be beneficial to know in what size enclosure kiwi stop thriving. How small is too small? Although there was extensive overlap for kiwi in the northern enclosure the reason may be more to do with the location of the water source rather than the size of the enclosure. More information on kiwi nocturnal movements would also be helpful in understanding how kiwi use their territories/home ranges. Although it was not possible to nocturnally observe birds for any extended period of time at Maungatautari, I believe there are areas where it could be done (Cunningham & Castro, 2011). Pine plantations or any areas with less understory would suffice. The observer/recorder needs to be able to follow at some distance so as not to disturb or 'spook' the bird. Also, knowing a female kiwi's role in reproduction would be helpful, i.e. does she excavate the nest or is it only the male. My research showed the male doing more of the mate preening, but what is the female's contribution with respect to pair bonding? Other beneficial studies might include looking at kiwi activity expenditure, i.e. using a pedometer to record the number of steps, so we have an idea of what kiwi are searching for. In conjunction with this, looking at seasonal prey abundance would be useful to understand probing conditions for kiwi during the dry seasons. Having a baseline for seasonal kiwi activity could be an indication of habitat quality as mentioned previously. As mentioned in Chapter 3, research identifying what specific behaviours contribute to kiwi activity and in what proportions would be beneficial. Identifying the activity of reproductive males that corresponds with successful nests would be useful to find the minimum incubation threshold.

8.4 Management implications

The results of this research can be applied to kiwi management throughout New Zealand and not just in fenced sanctuaries. Access to permanent water courses helps ensure food availability while coarse woody debris creates habitat for sheltering. These requirements can help estimate carrying capacities when restoring populations.

The current kiwi recovery plan wants to, "…increase New Zealanders' connections with kiwi…" (Germano et al., N.D.). An excellent way to accomplish this would be to let people see what kiwi do. As kiwi are not always observable in their natural habitat, video footage is a great way to increase awareness. Further studies documenting kiwi behaviour and allowing the public to access this footage would be a way to advocate for the species and increase connectivity.

Although the outcomes of this study are a positive assurance for Maungatautari that their kiwi programme is, in fact, benefitting kiwi, it is a good benchmark for other projects looking to establish new kiwi populations or improve existing sites.

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Appendix 1 - Examples of female kiwi activity recorded on the datalogger.
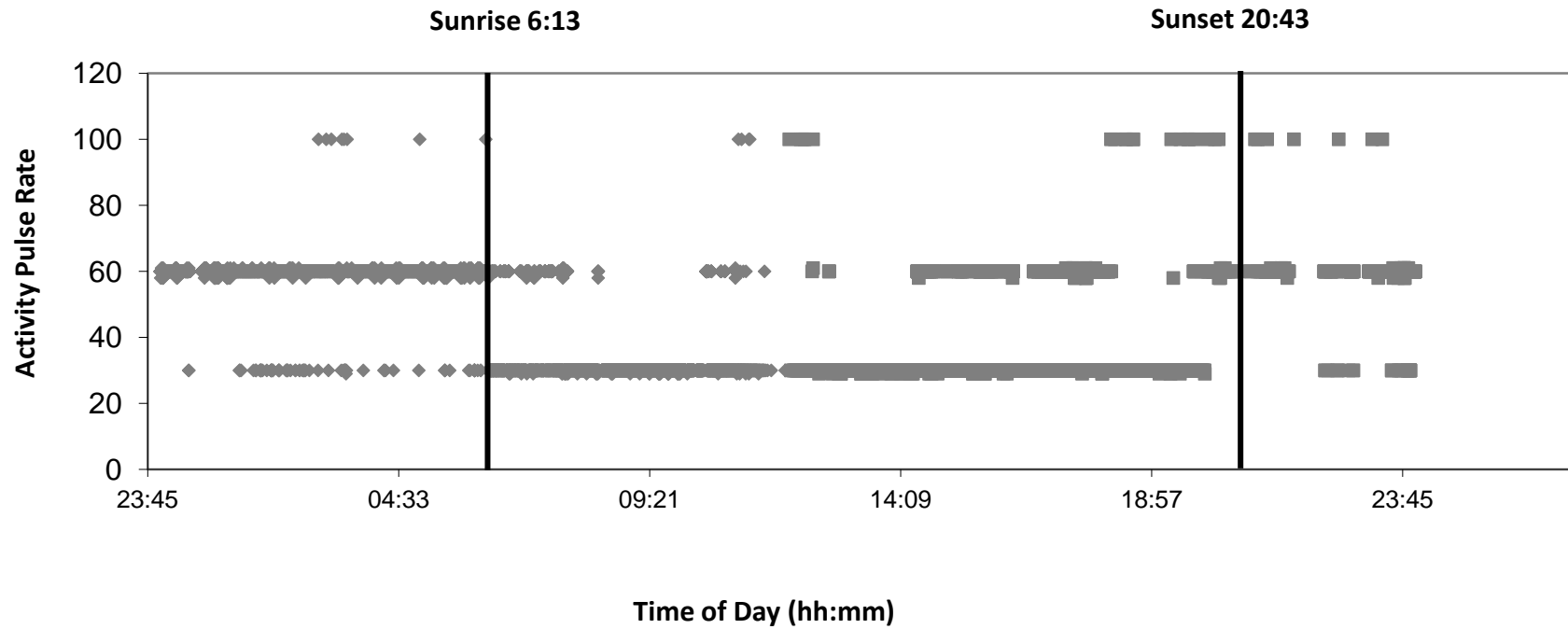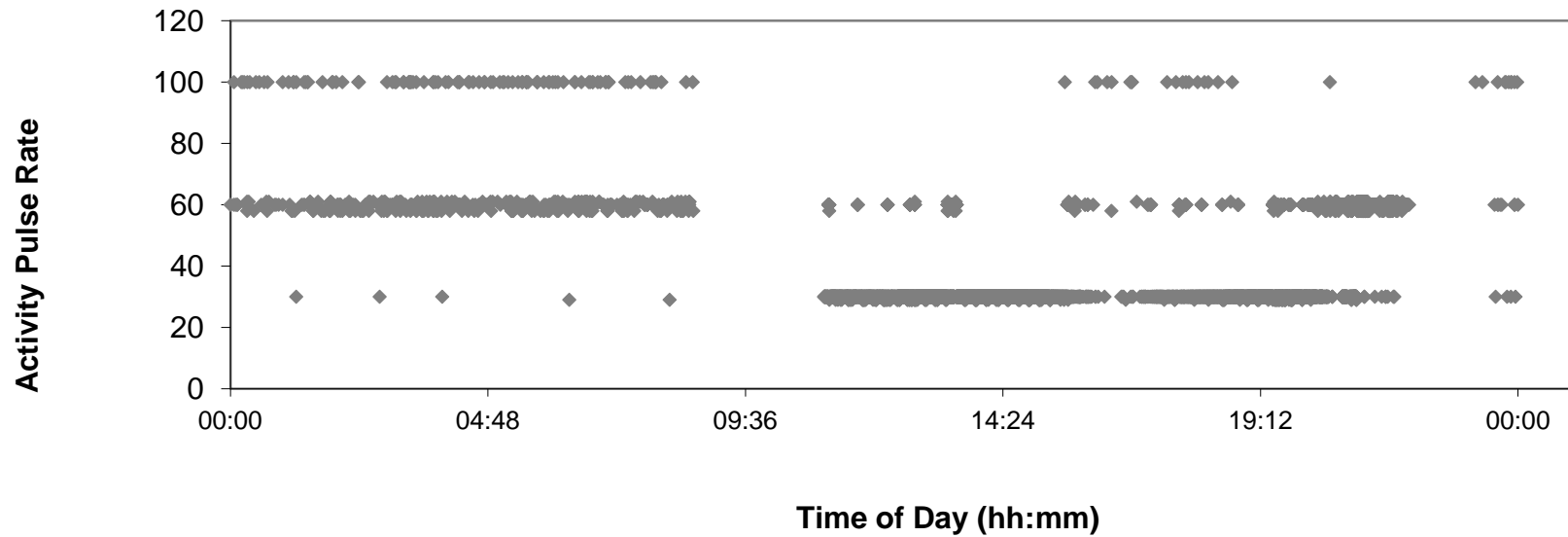

Fig. A1.1- Example of Female Activity (Cassidy) over the course of 7 January 2009. Inactive= 30, active= 60 pulses, out of range= 100 pulses. Time of sunrise and sunset indicated by vertical lines.
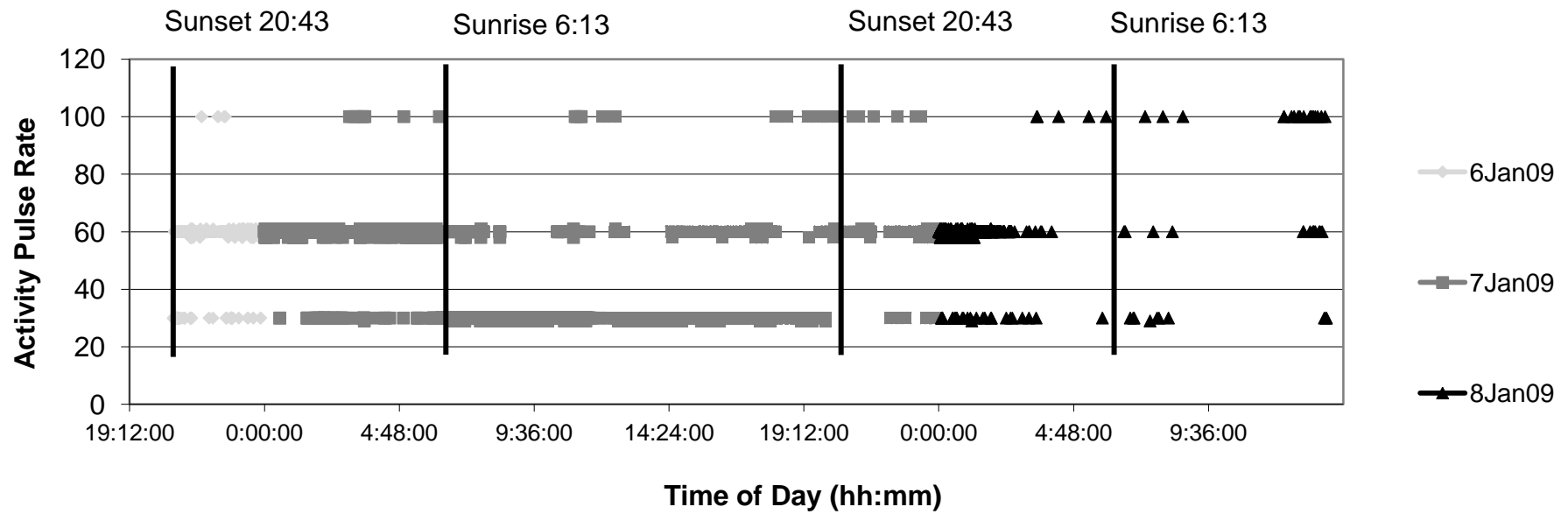
Fig. A1.2- Example of Female Activity (Cassidy) from 6-8 January 2009. Inactive= 30 pulses, active= 60 pulses, out of range= 100 pulses. Time of sunrise and sunset indicated by vertical lines.

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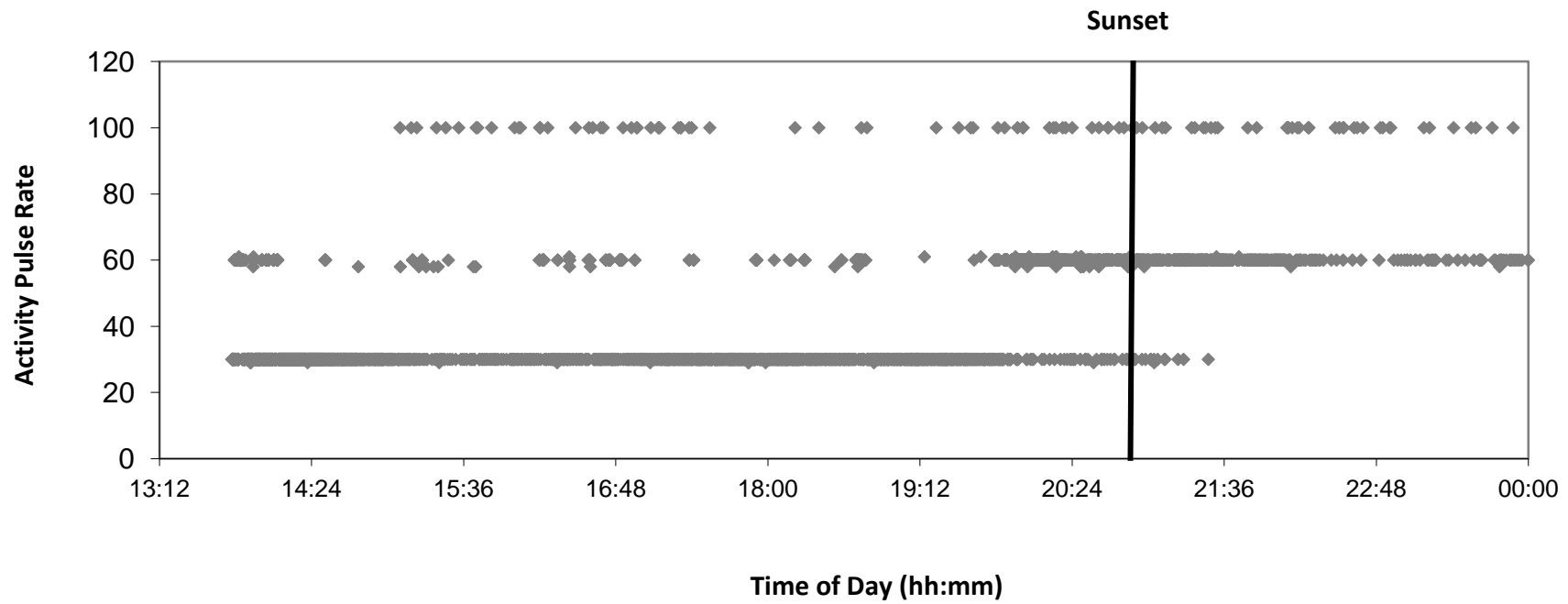
Fig. A1.3- Example of Female Activity (Karuwai) over the course of 19 January 2009. Inactive= 30 pulses, active= 60 pulses, out of range= 100 pulses. Time of sunset indicated by vertical line.

Fig. A1.4- Example of Female Activity (Horokio) 11 December 2008. Inactive= 30 pulses, active= 60 pulses, out of range= 100 pulses. Time of sunrise and sunset indicated by vertical lines.

Appendix 2- Maps of individual kiwi shelter locations, overlapping home ranges and paired bird home ranges.

The following are a series of maps that show the locations of individual kiwis' daytime shelters in both the northern and southern enclosures. Although the shelters were not all located on consecutive days, the attached numbers correspond to the legend and indicate the order in which the kiwi were found and the date that the bird was in the shelter (Figs. A2. A- A2.F, Figs. A2.I-A2.P). Figs. A2.G and A2.H and Figs. A2.Q and A2.R highlight the male and female home ranges using the convex polygon method. The remainder of the Figs. (A2.S, A2.T and A2.U) show the shelter locations of all paired birds.
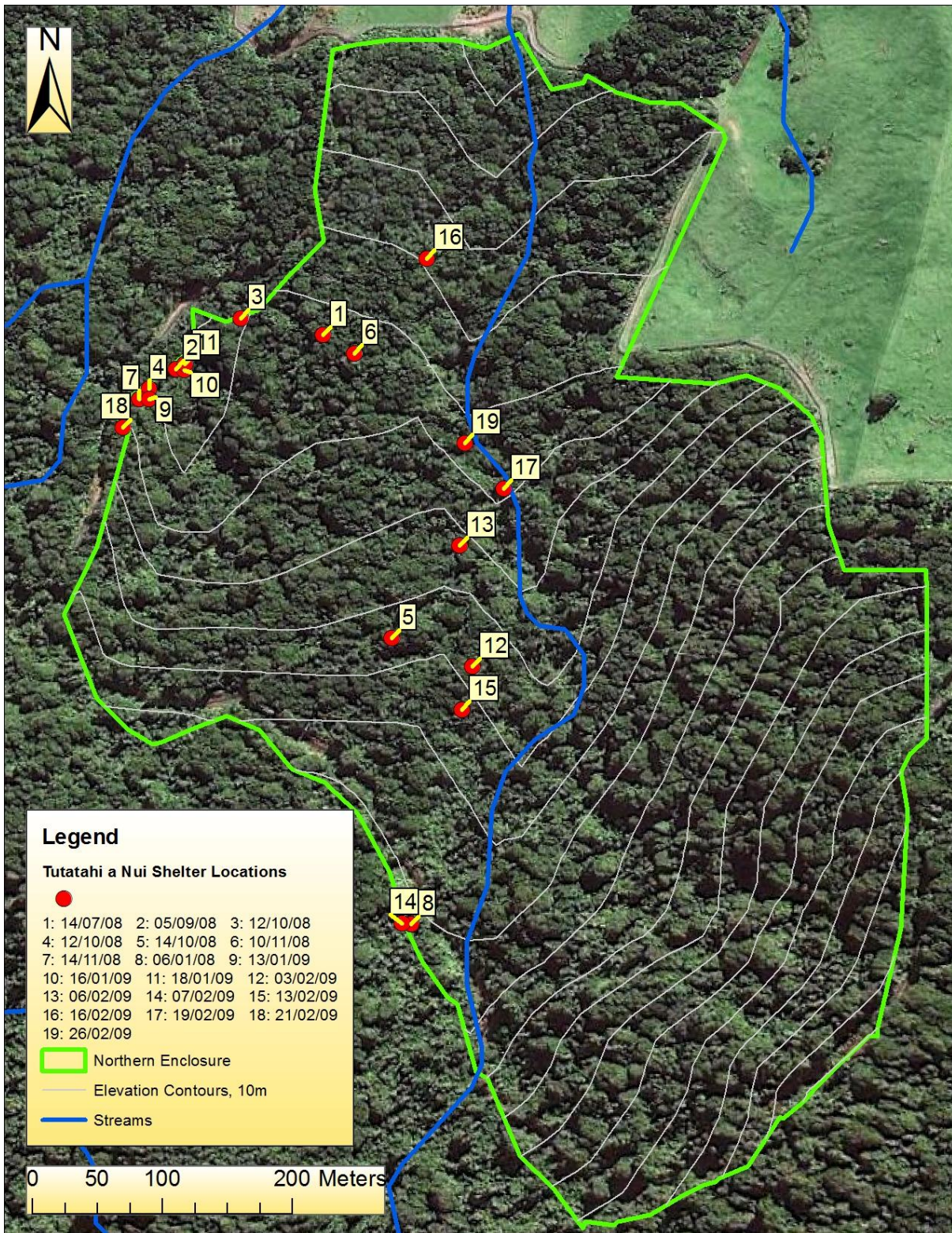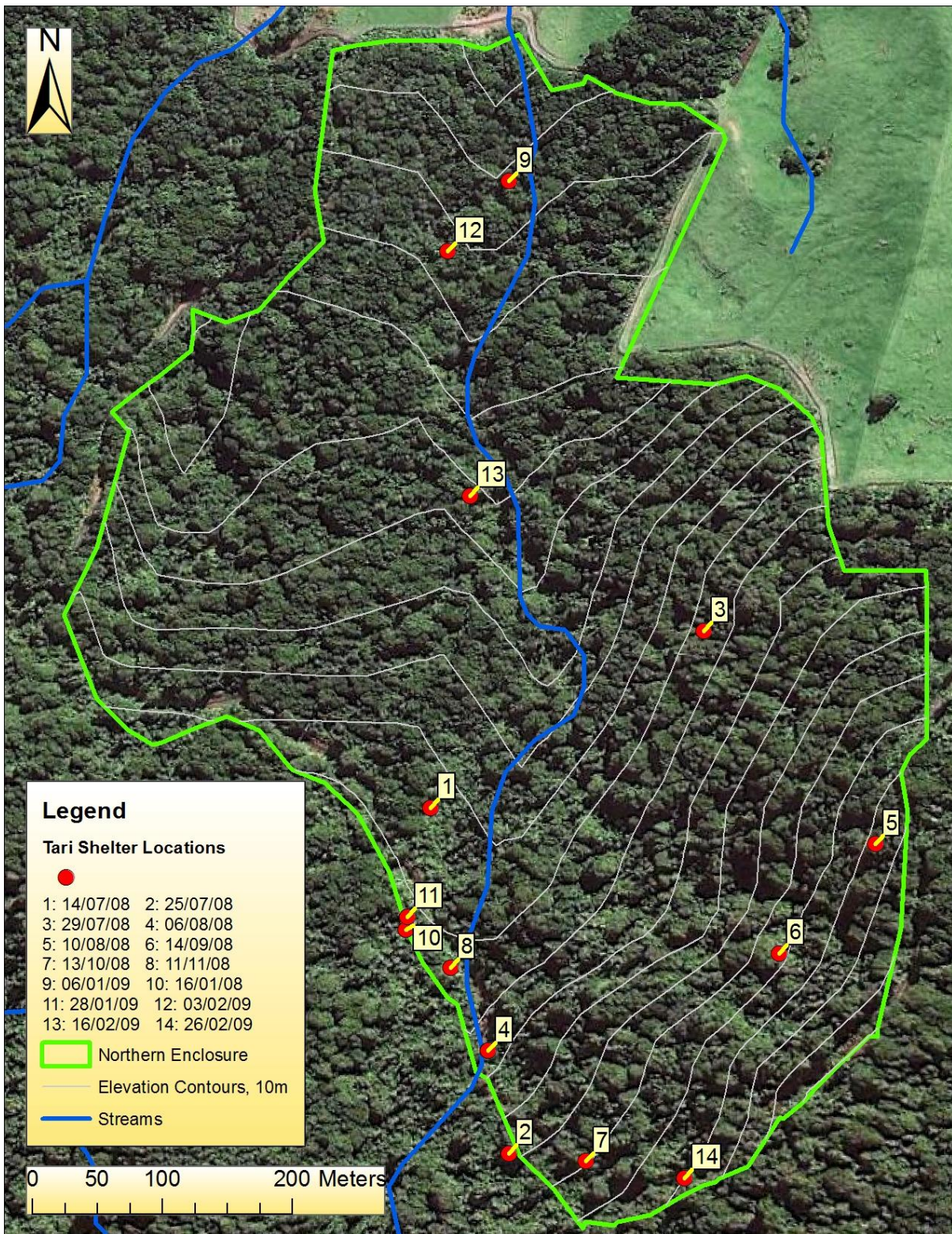
Fig. A2.A-Tuatahi a Nui

Fig. A2.B- Tari
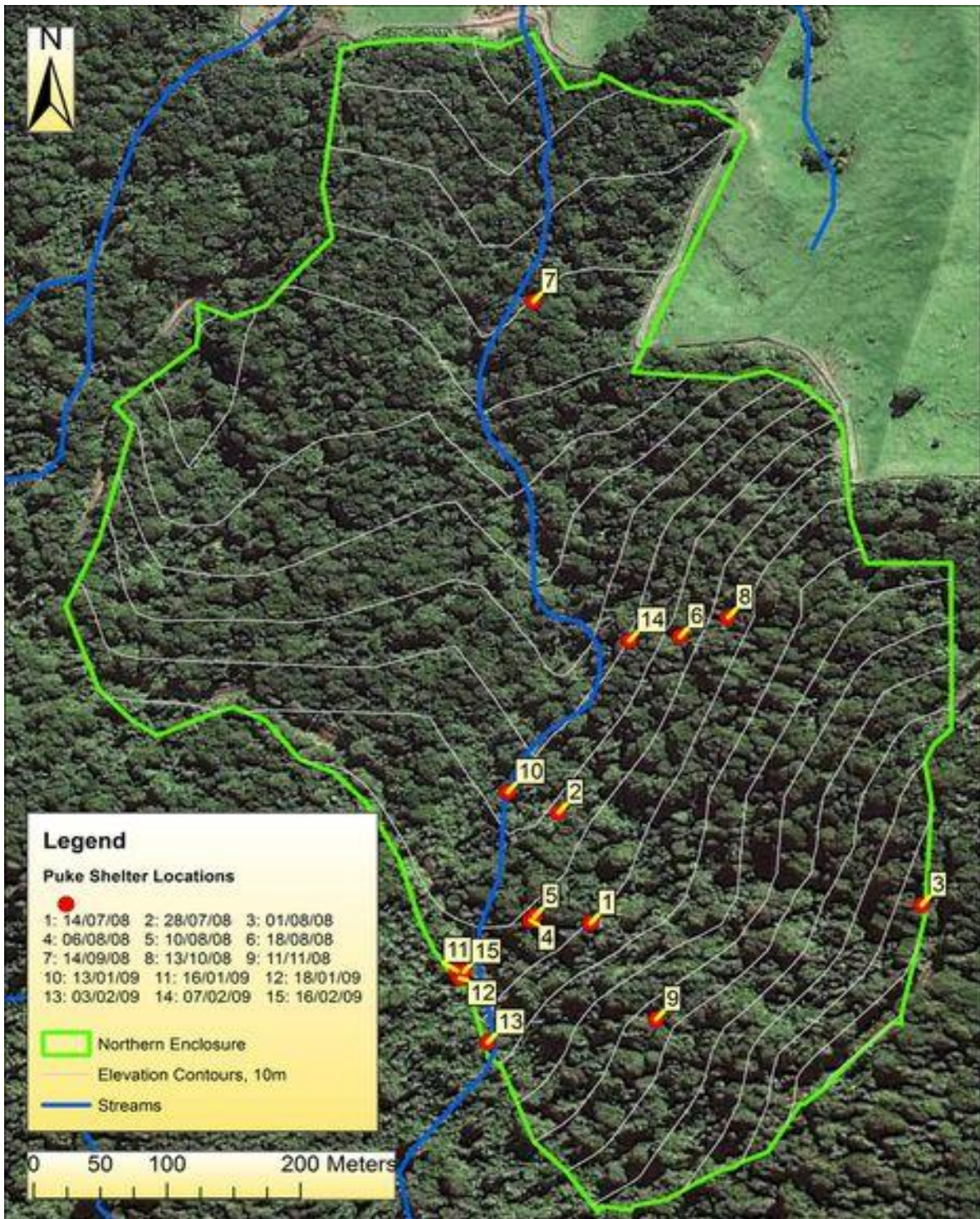
Fig. A2.C- Puke
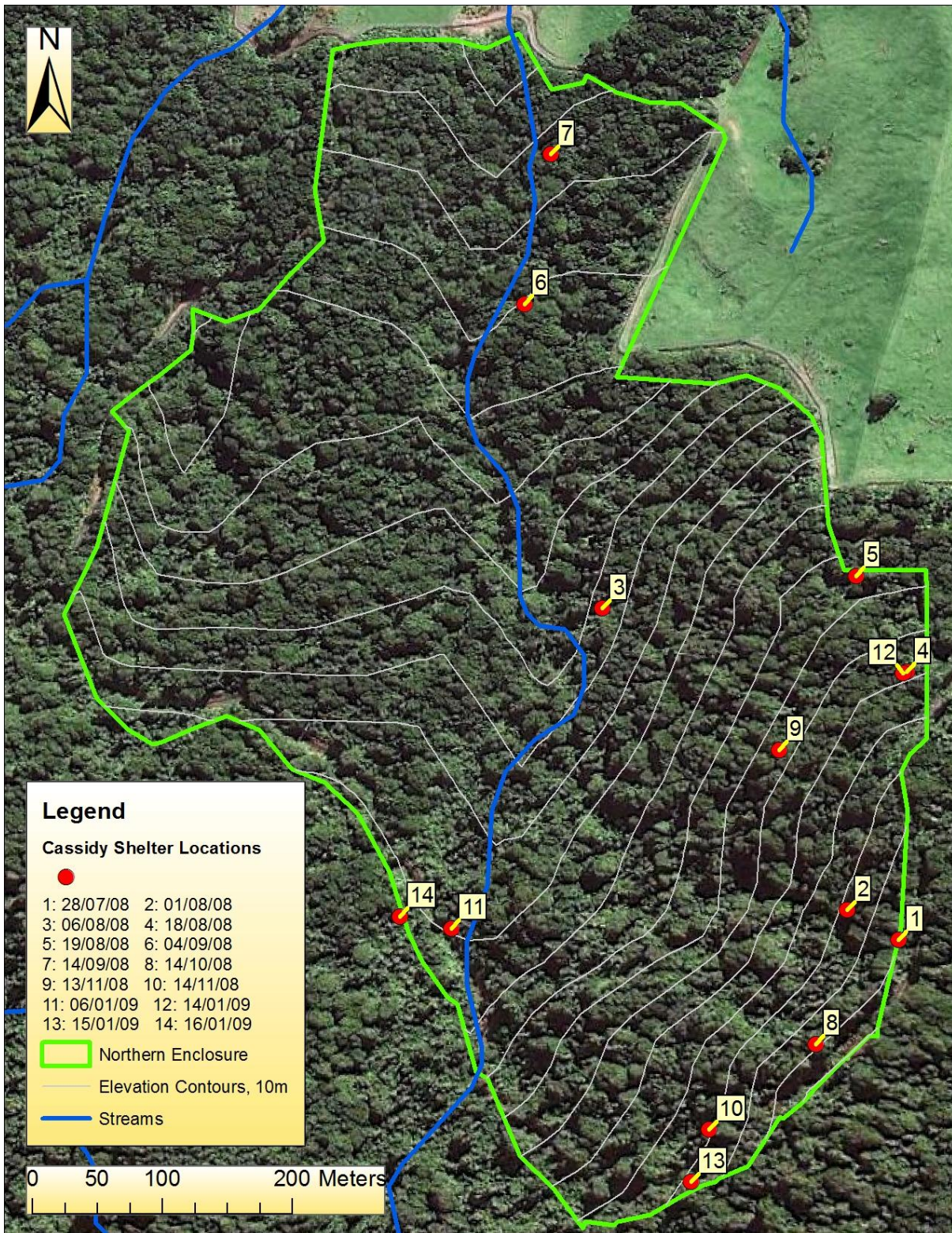
Fig.A2.D- Cassidy
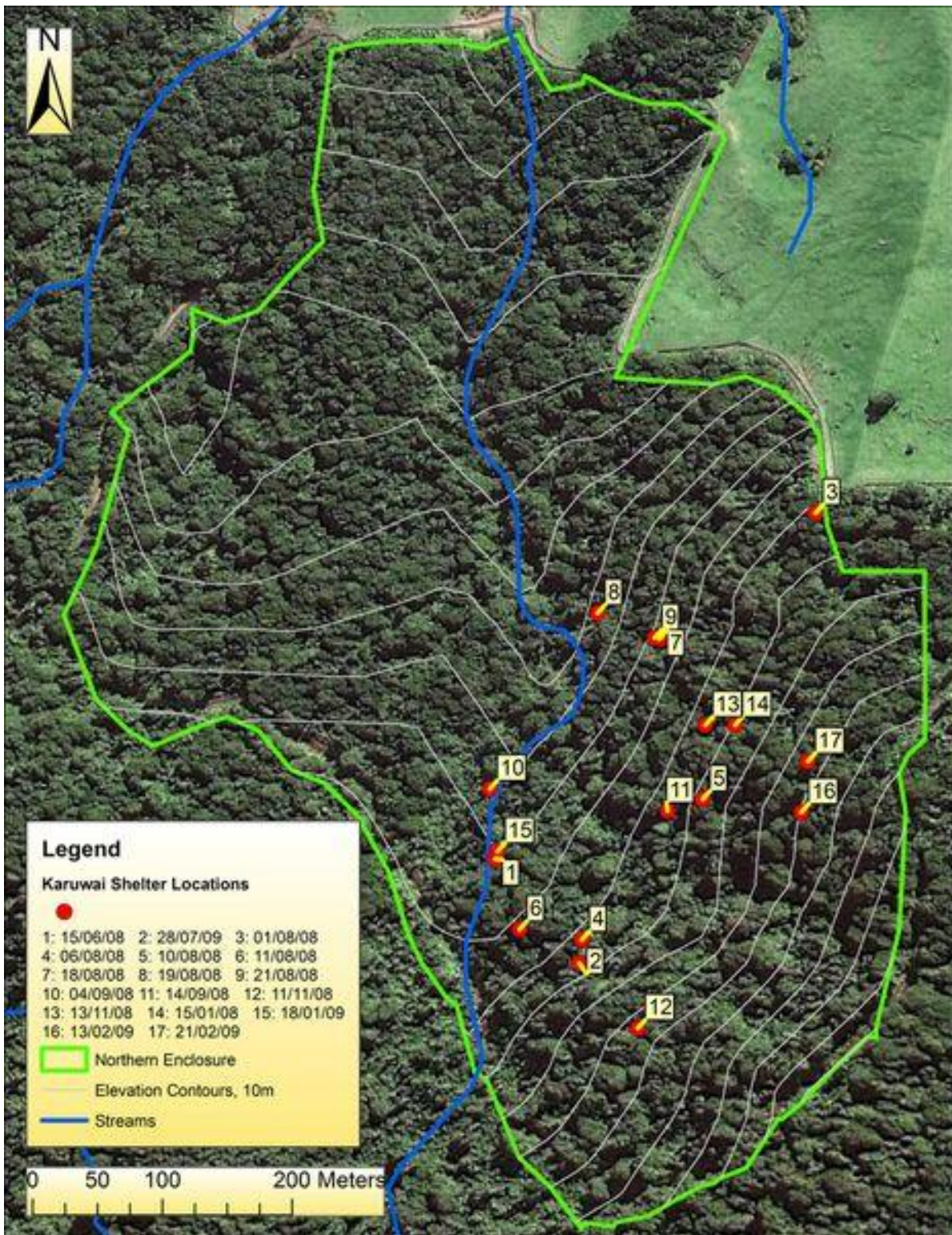
Fig.A2.E- Karuwai
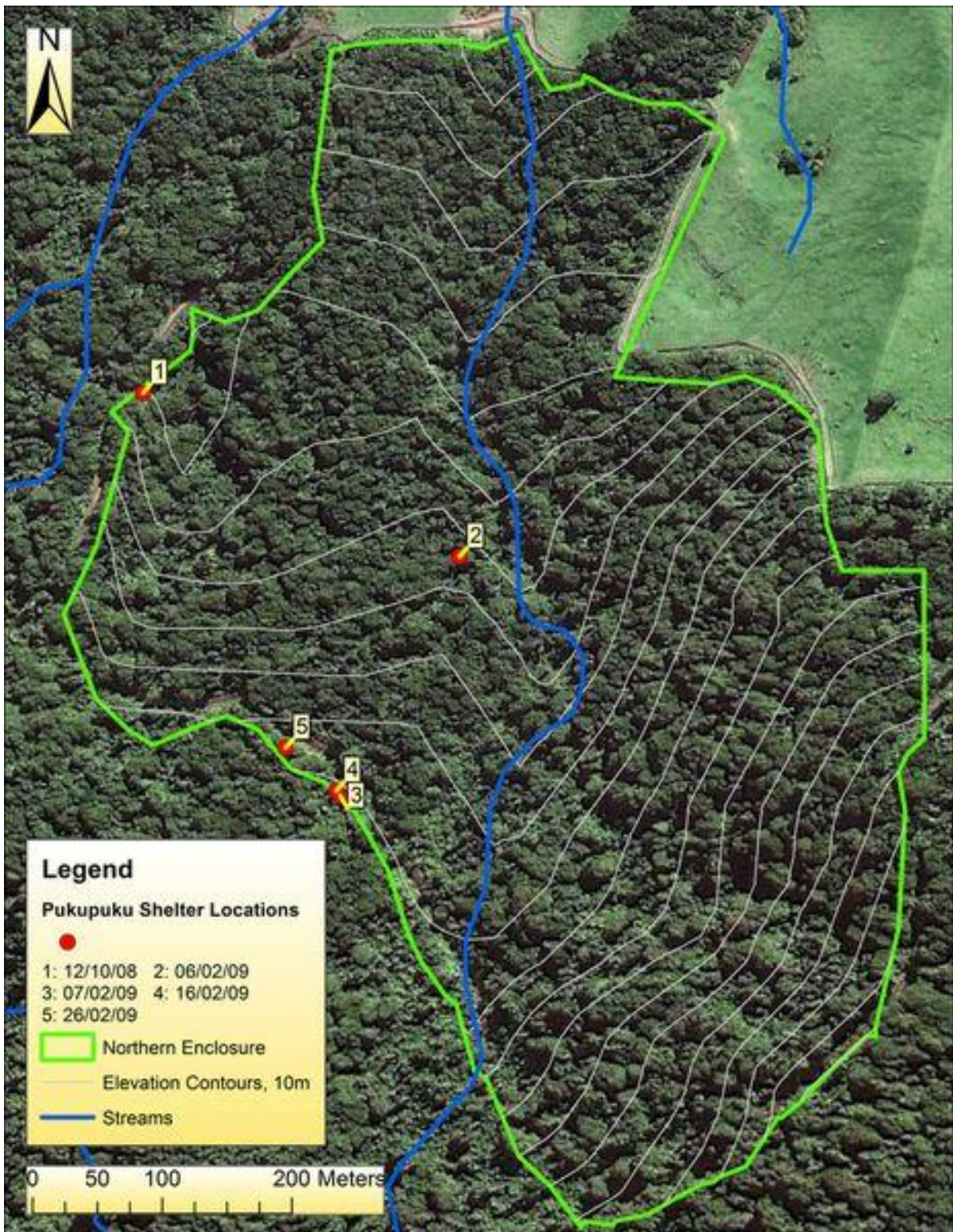
Fig.A2.F- Pukupuku
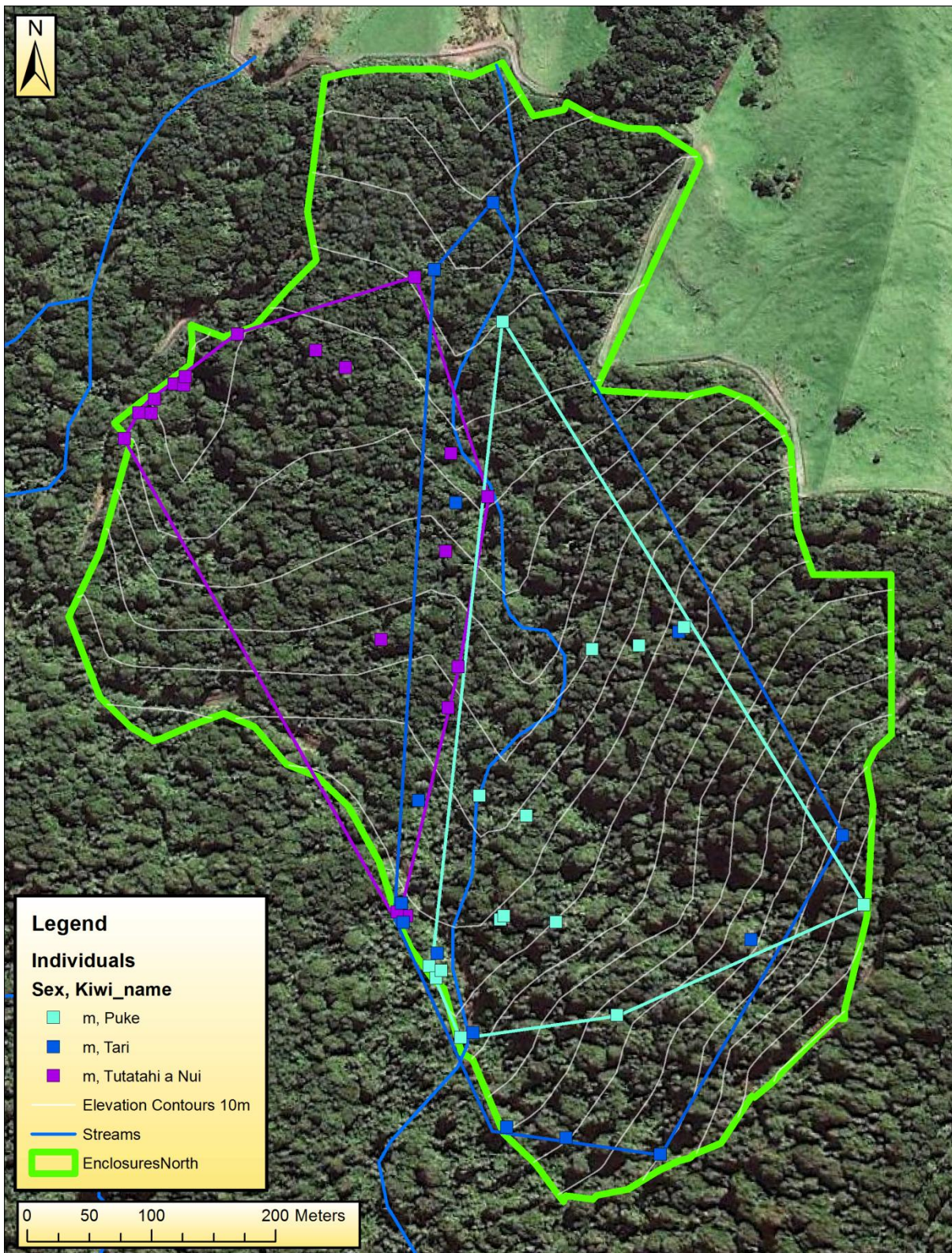
Fig.A2.G- Male territory overlap in the northern enclosure

Fig.A2.H- Female territory overlap in the northern enclosure

Fig.A2.I- Elmo
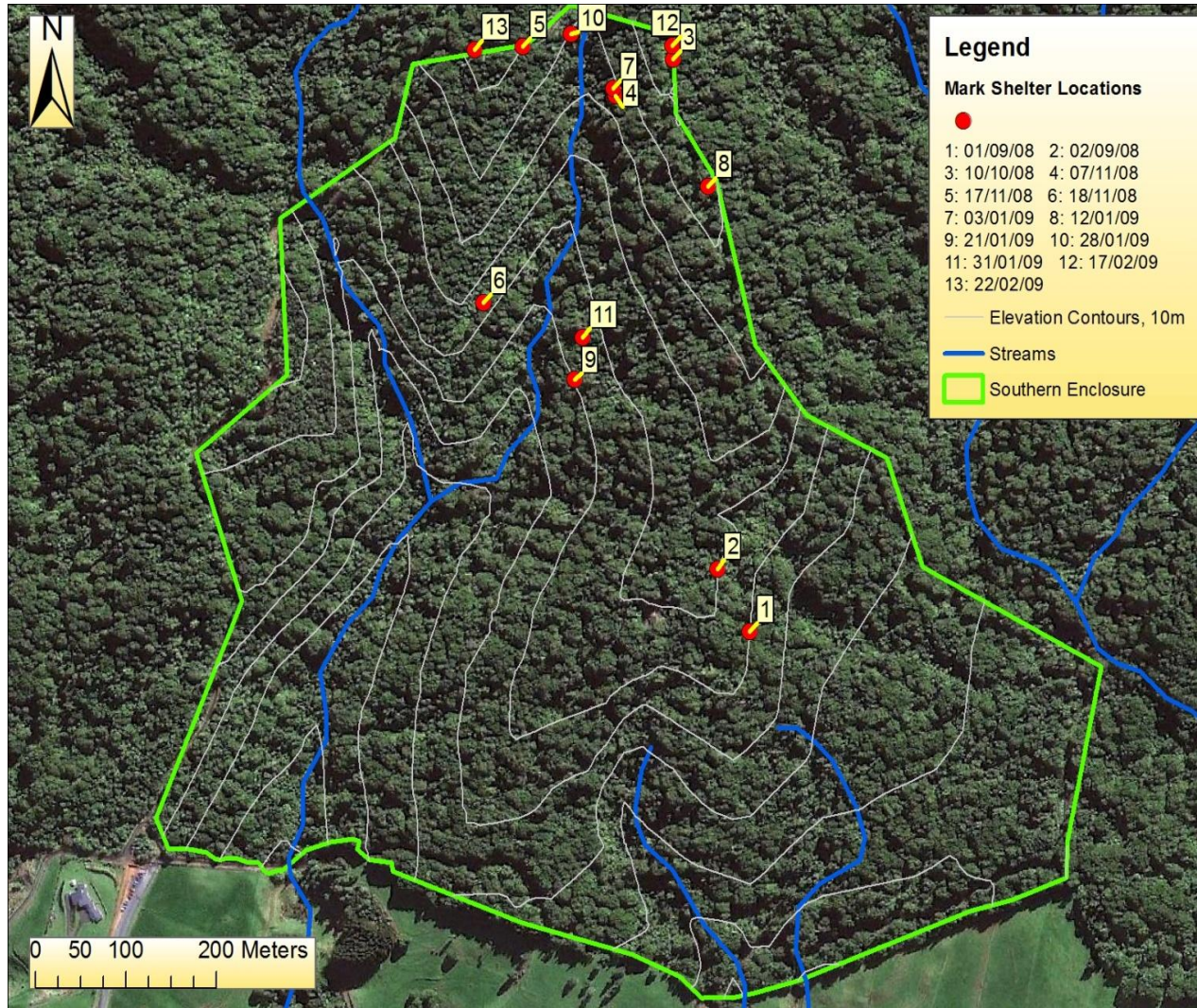
Fig.A2.J- Mark

Fig.A2.K- Parure

Fig.A2.L- Robin
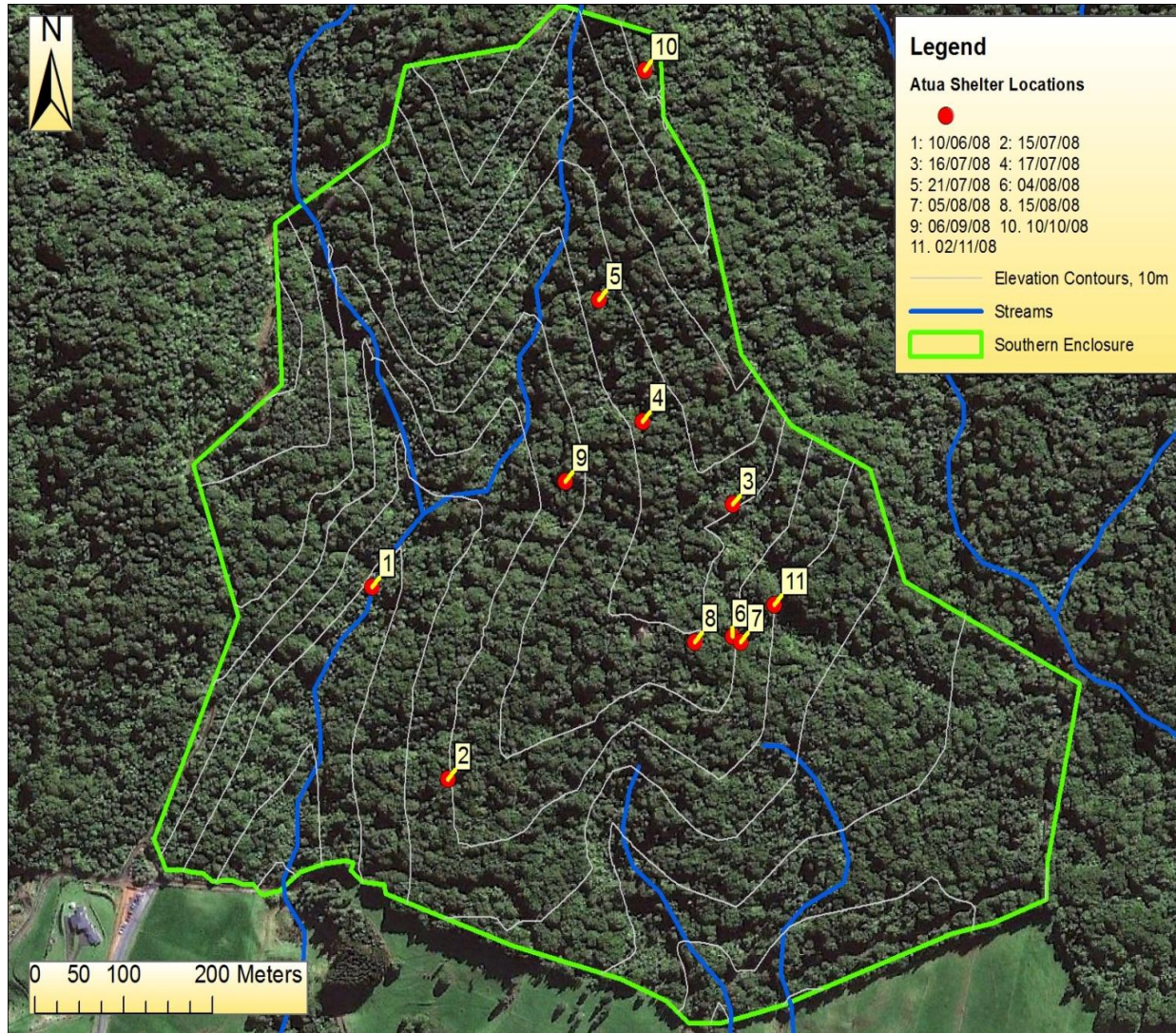
Fig.A2.M- Atua
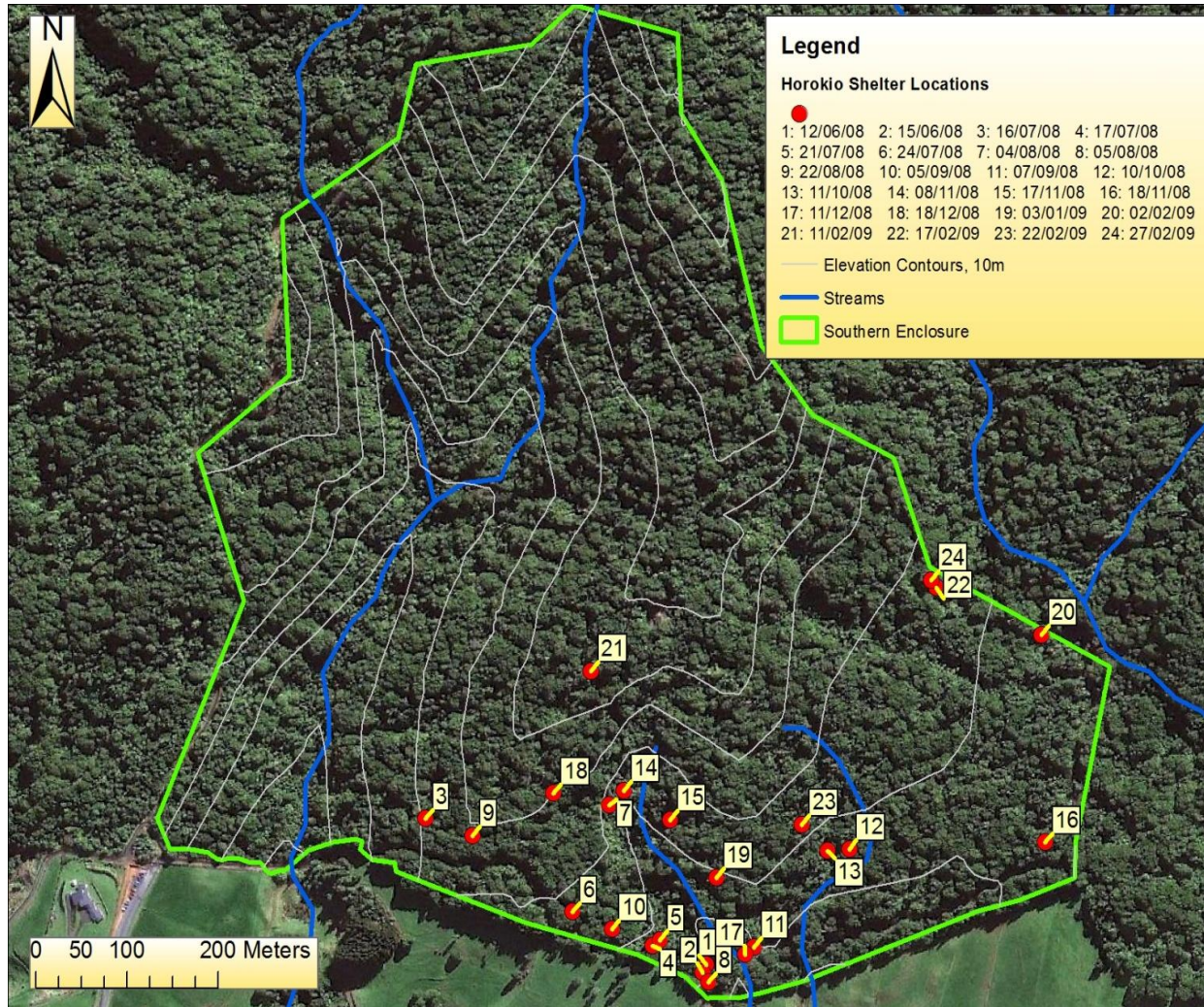
Fig.A2.N- Horokio
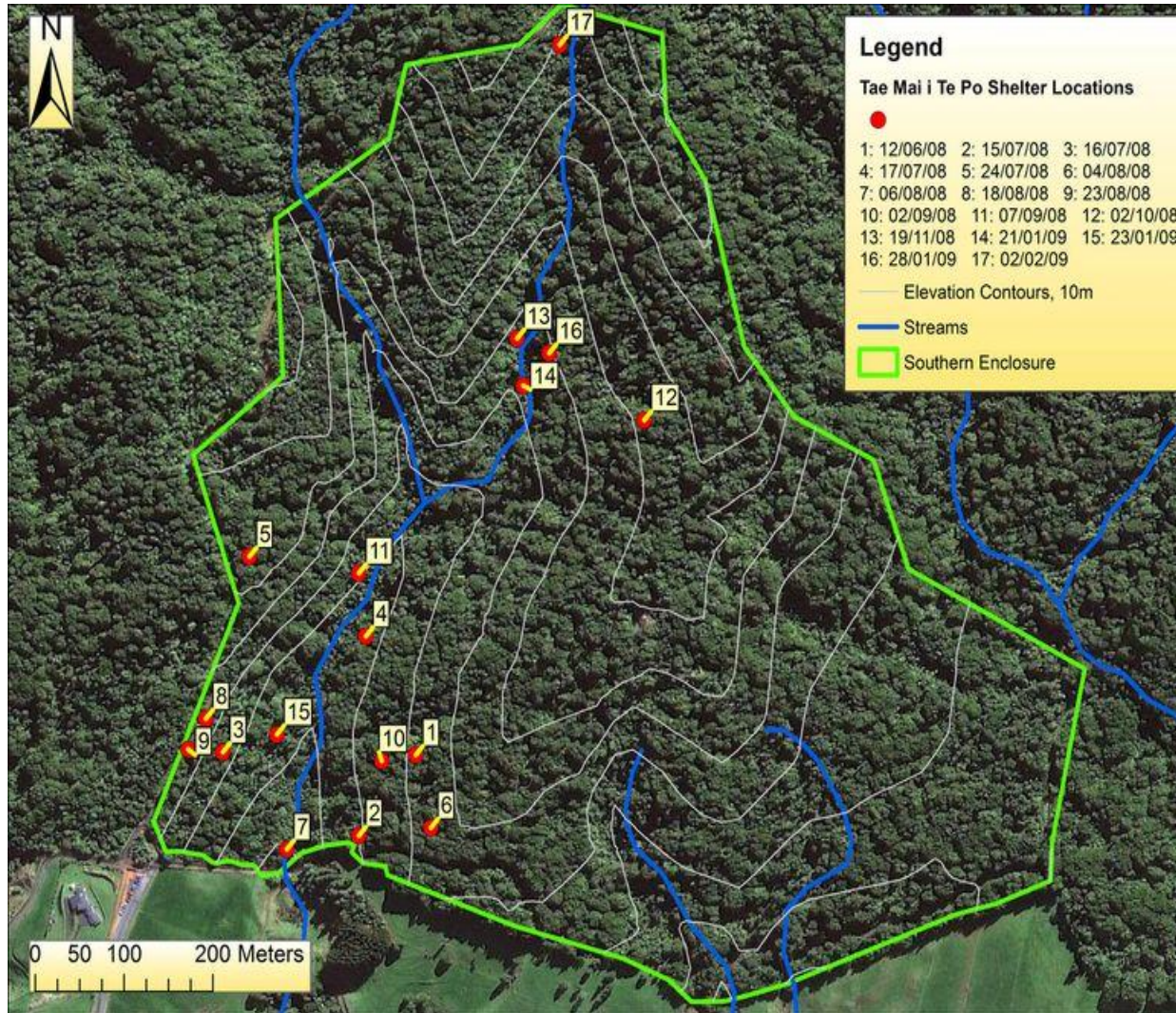
Fig.A2.O- Tae mai i te po
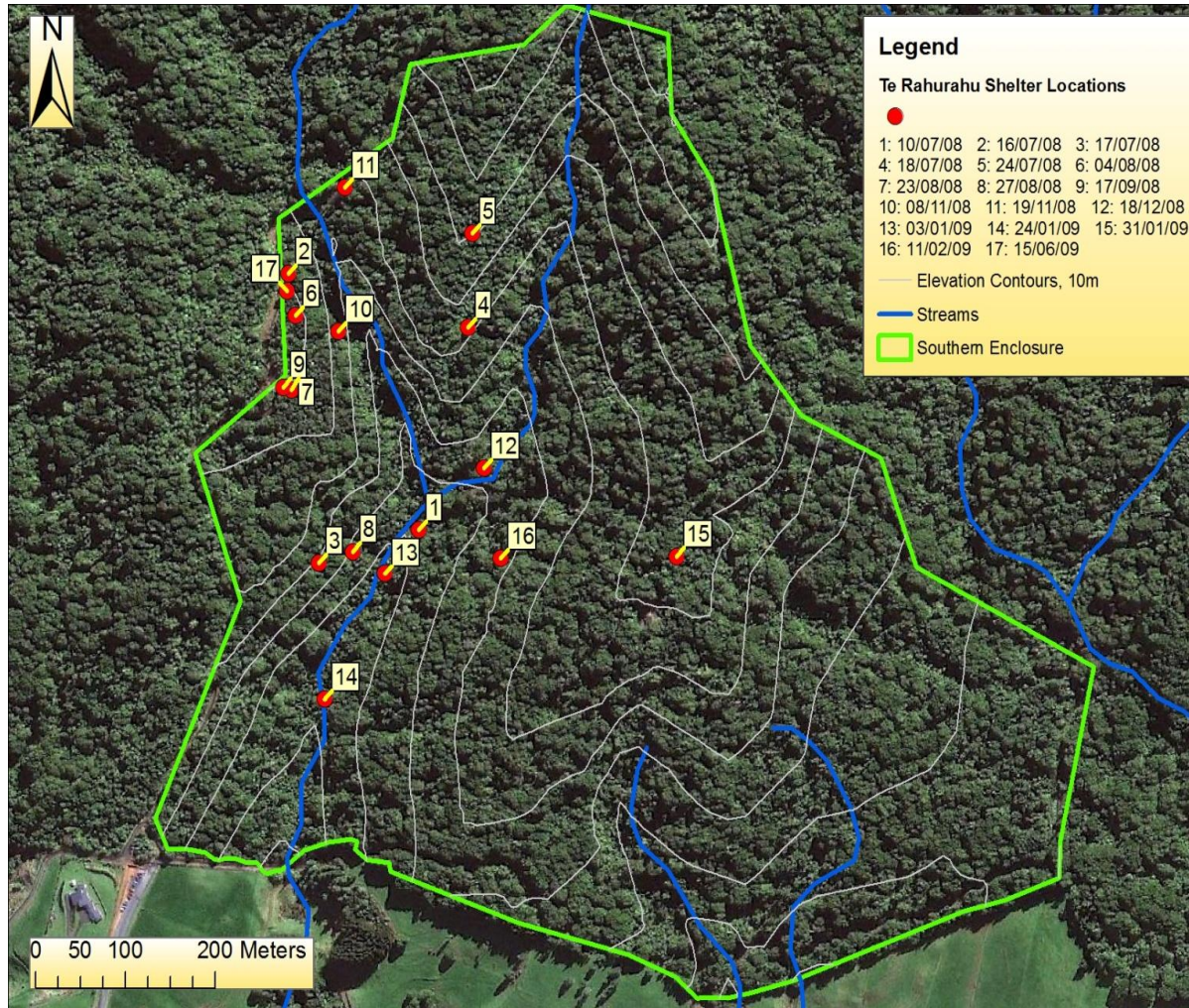
Fig.A2.P- Te Rahurahu
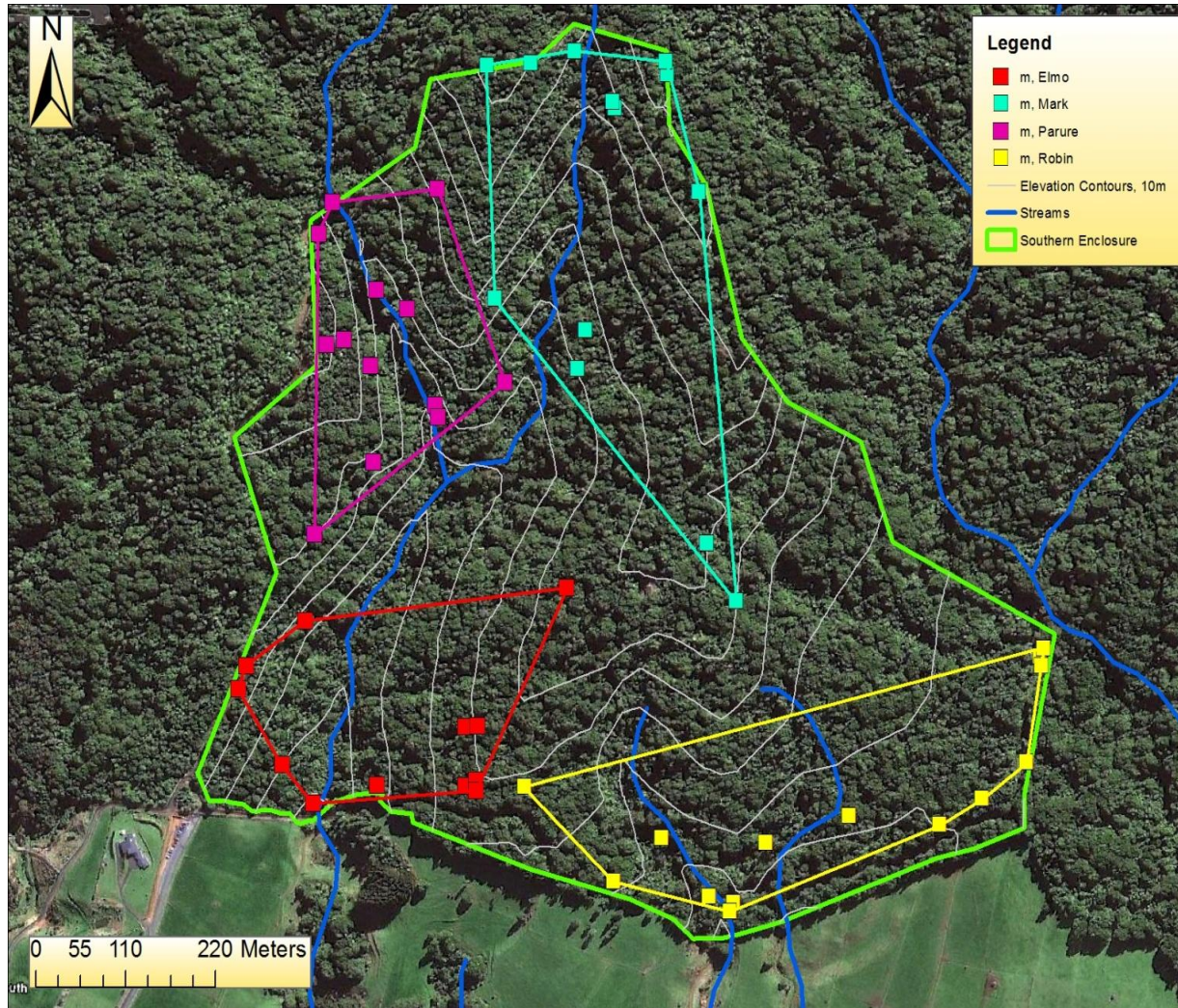
Fig.A2.Q- Male territory overlap in the southern enclosure
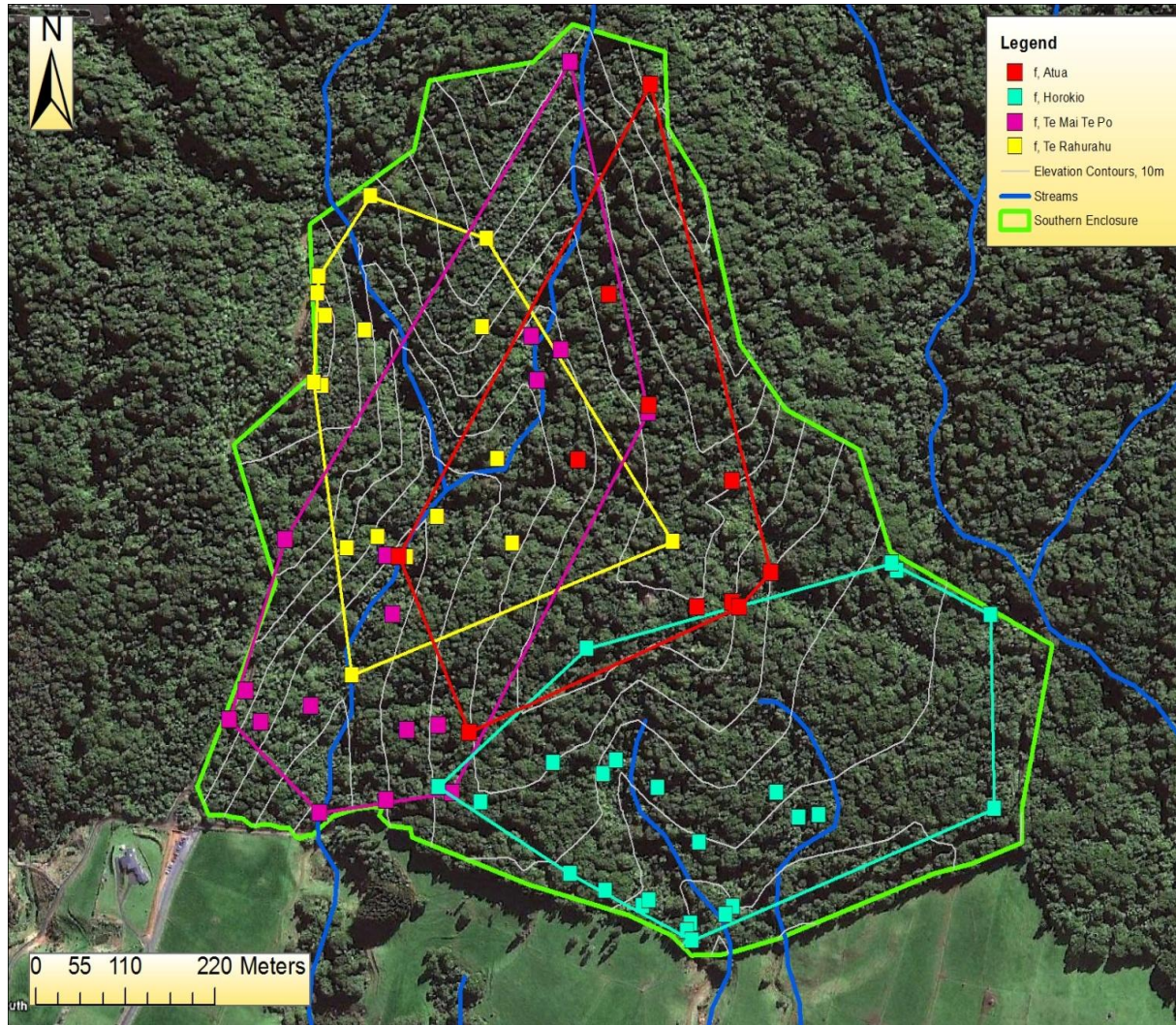
Fig.A2.R- Female territory overlap in the southern enclosure
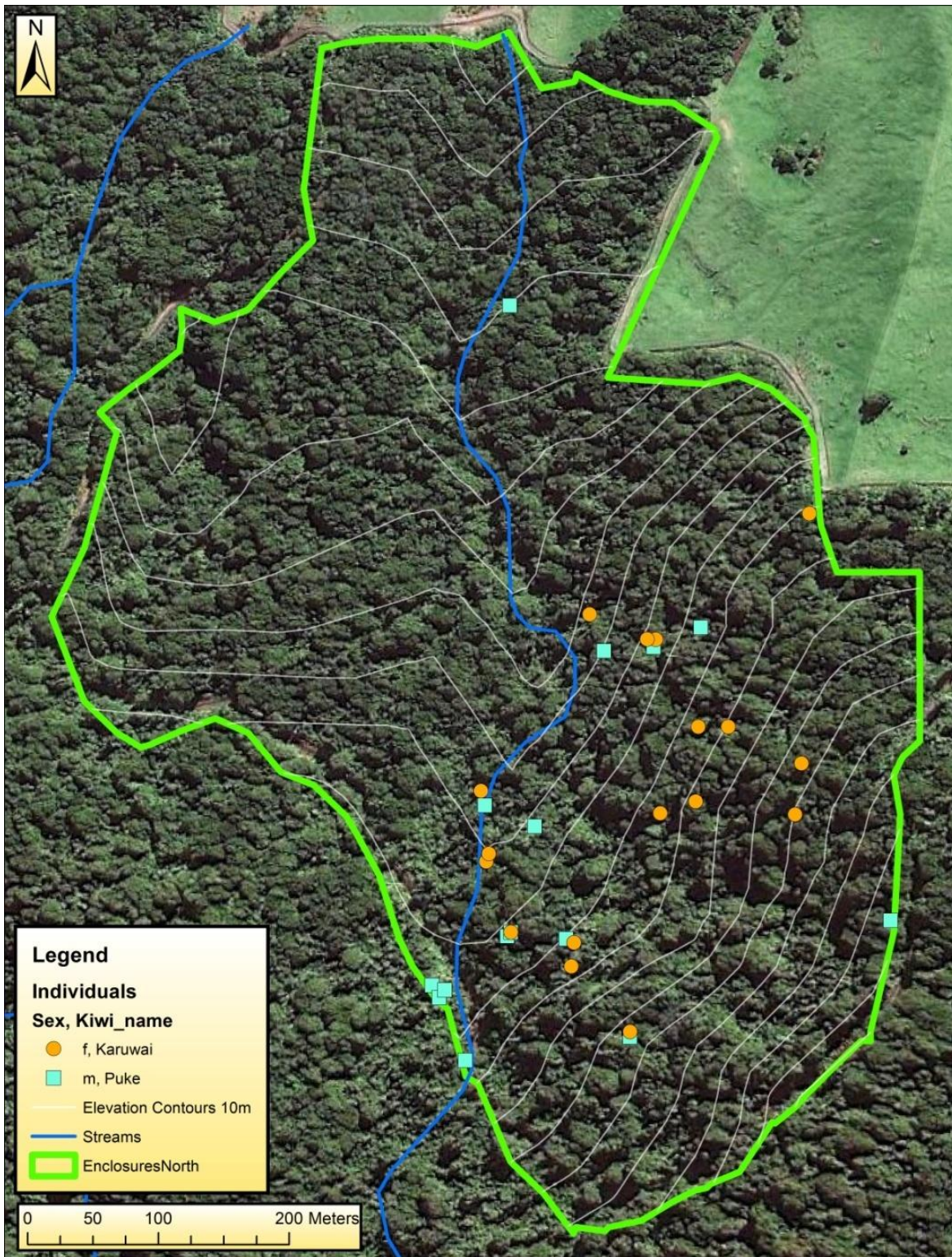
Fig.A2.S- Shelter locations of known paired kiwi in the northern enclosure
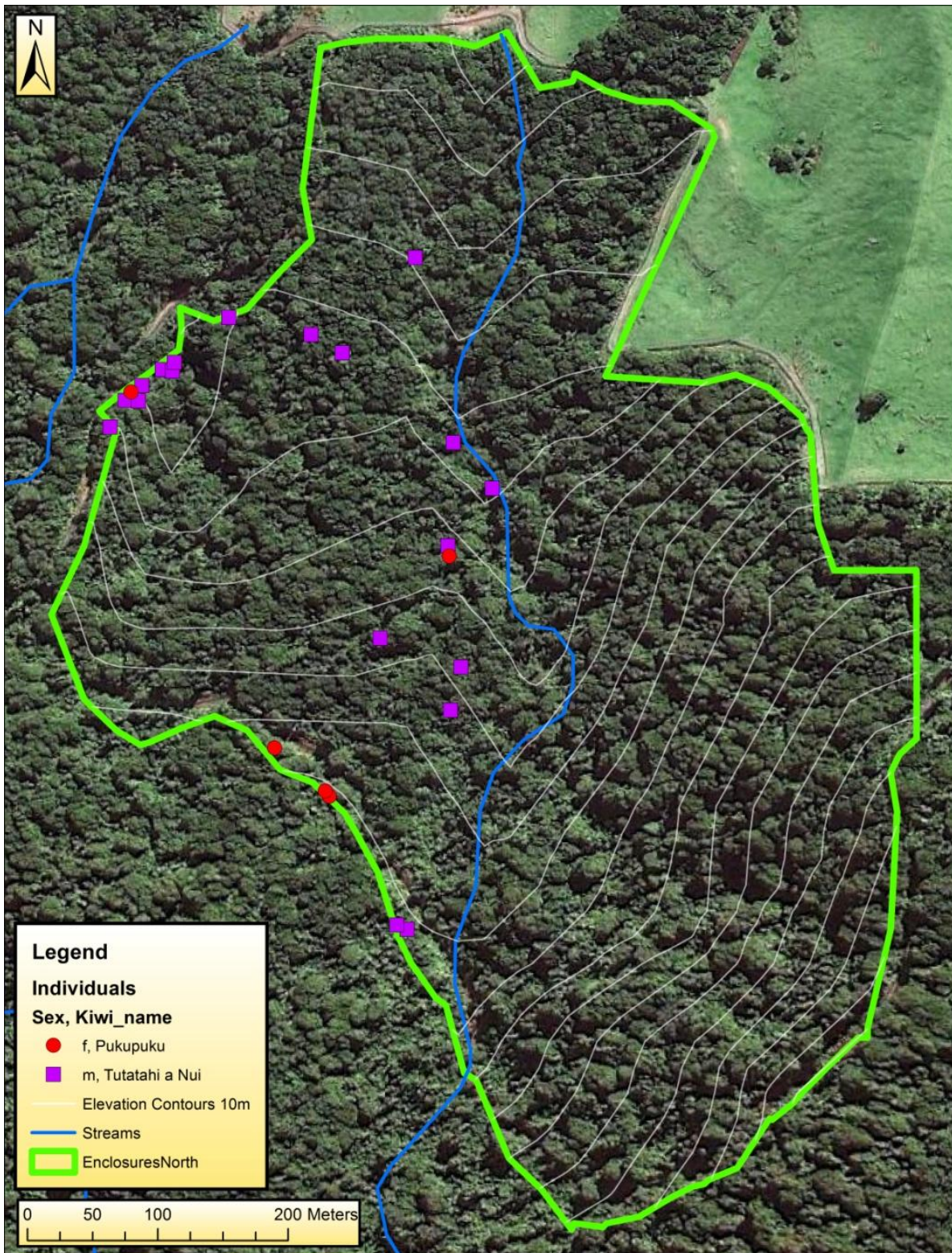
Fig.A2.T- Shelter locations of known paired kiwi in the northern enclosure
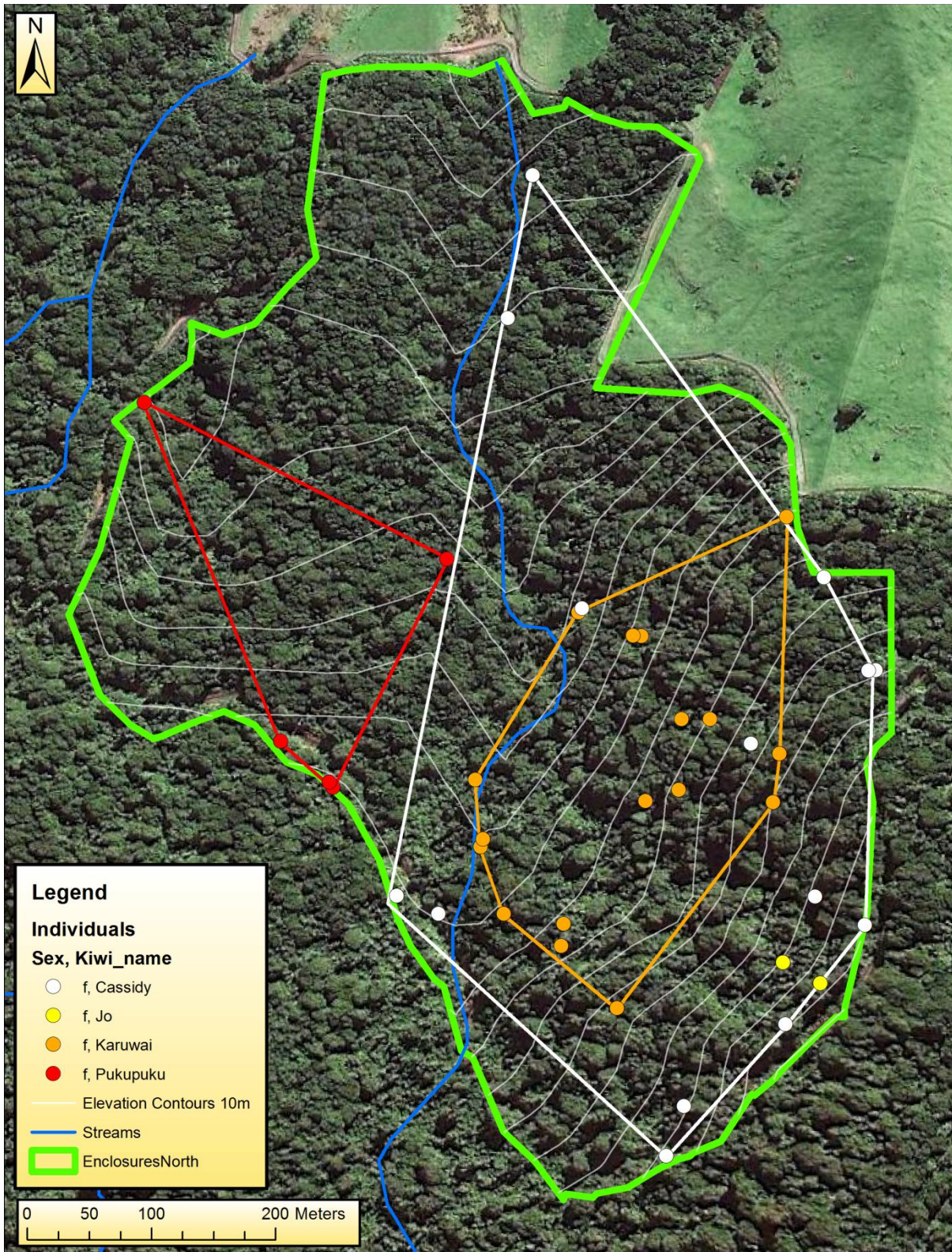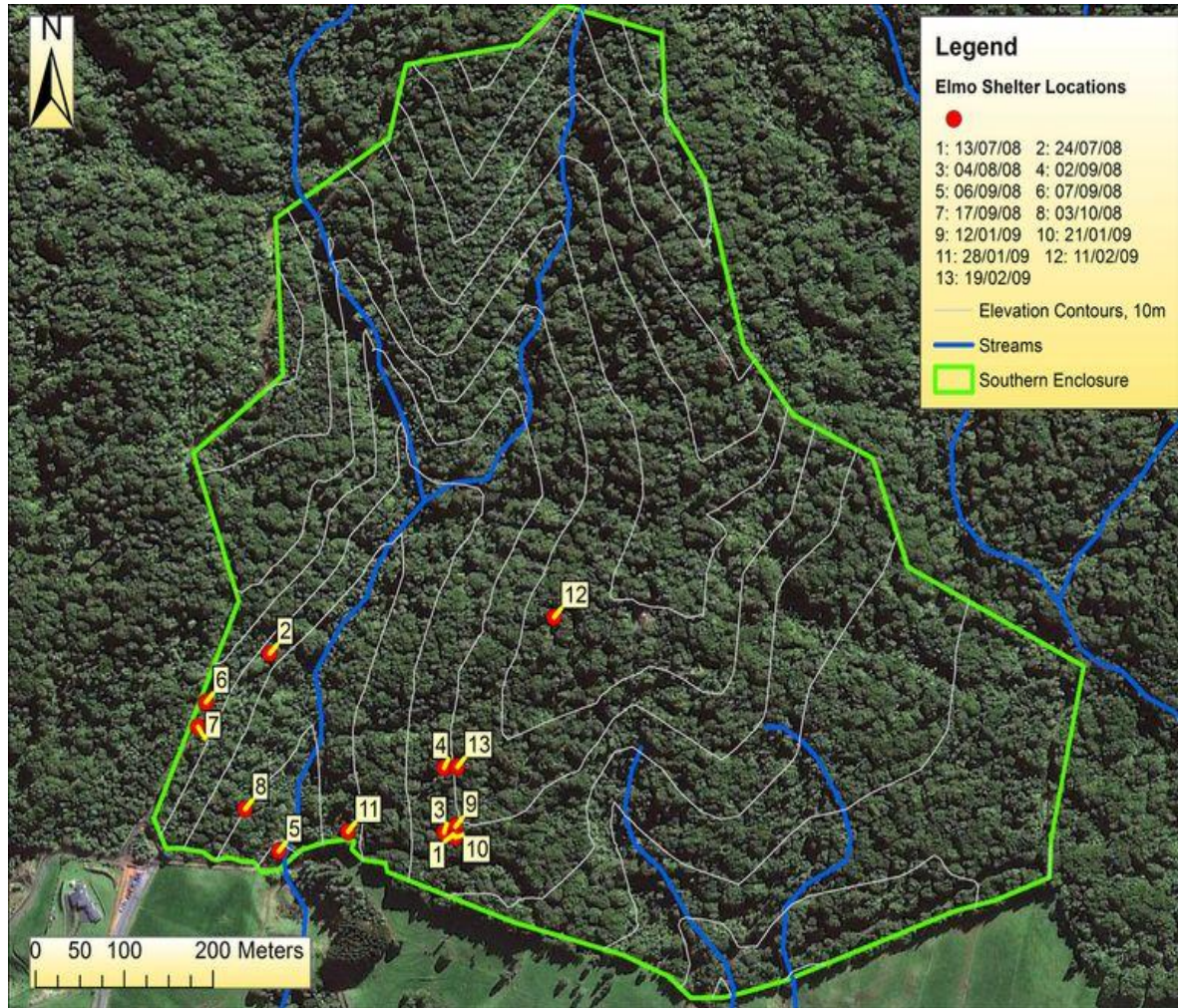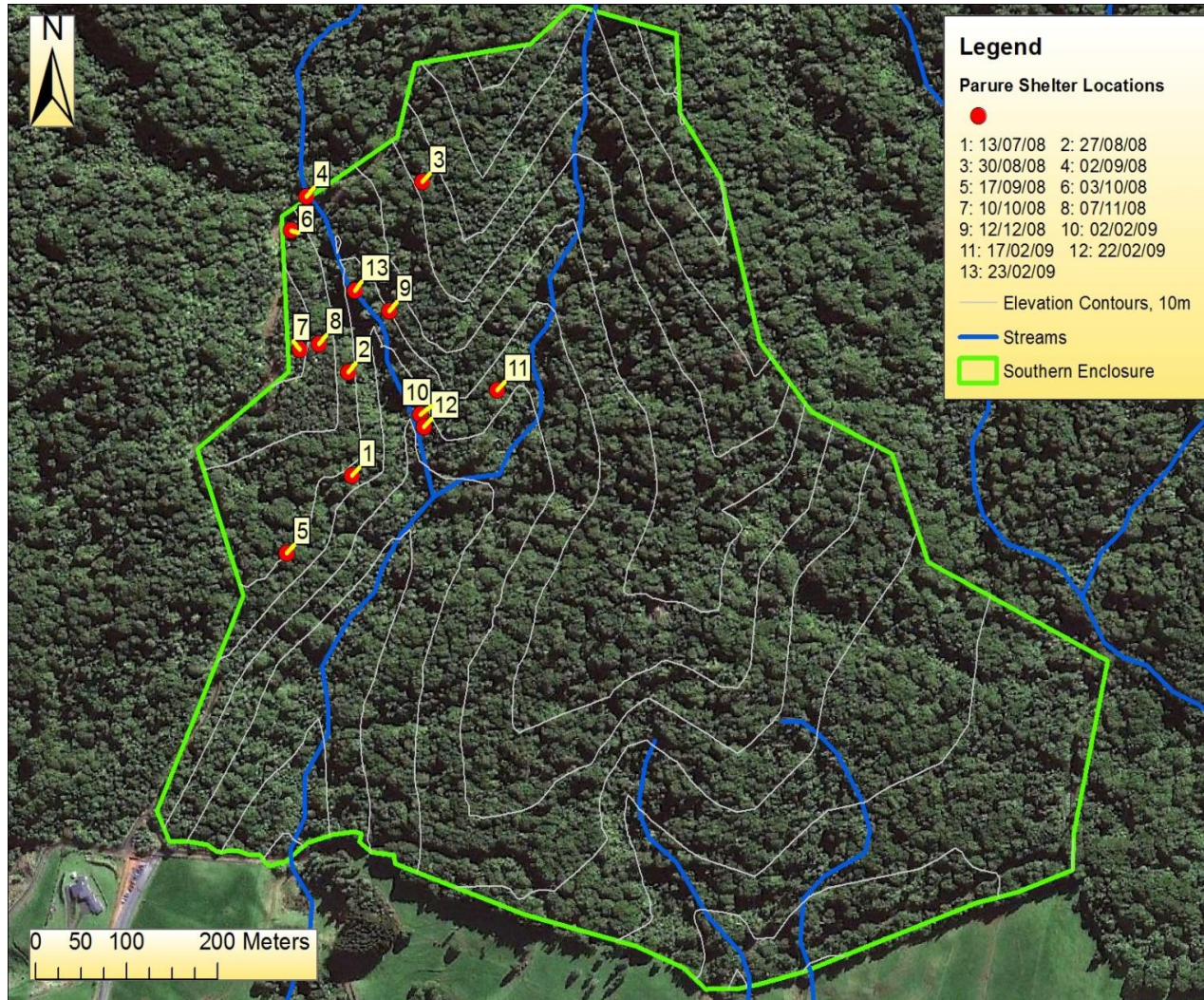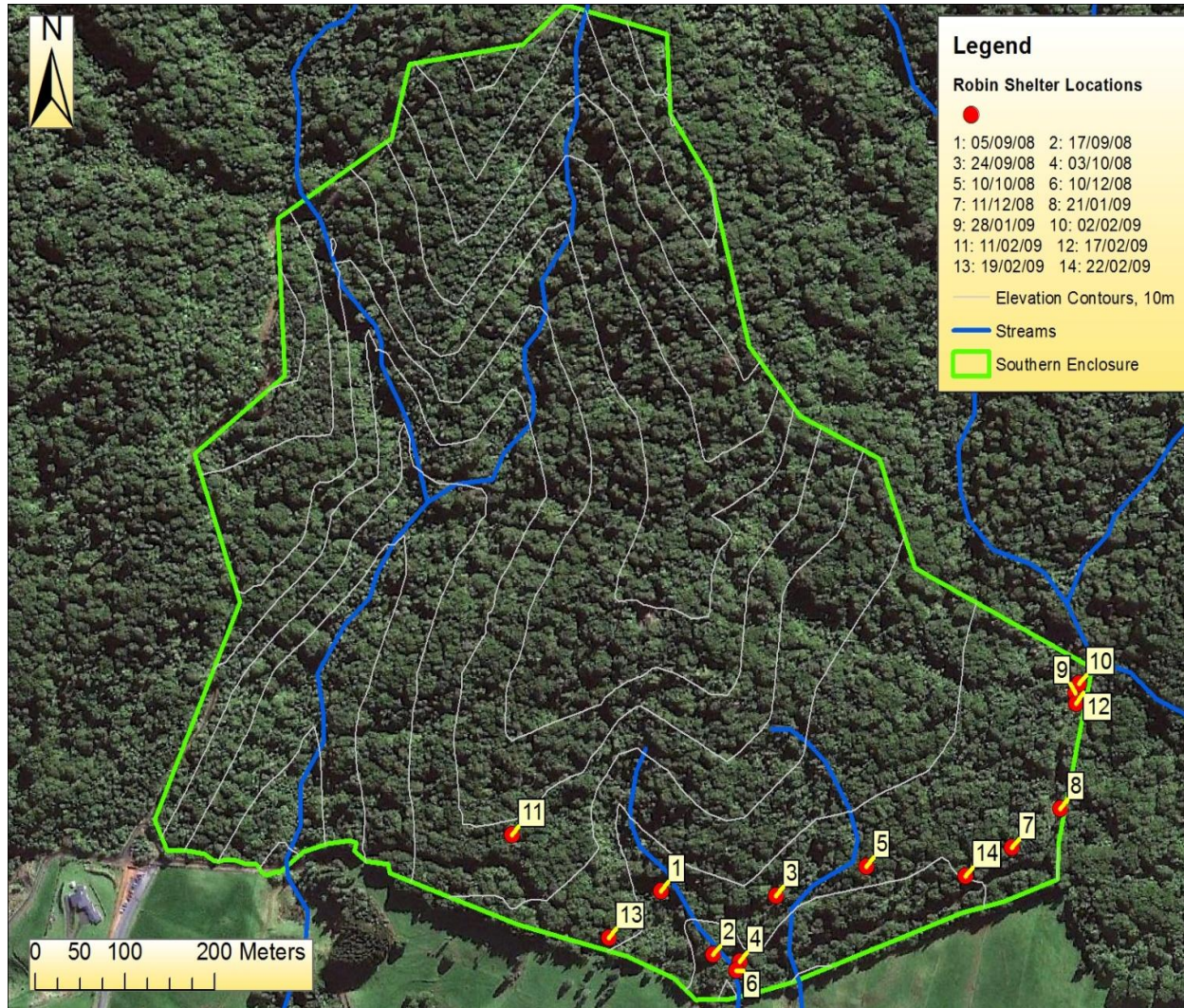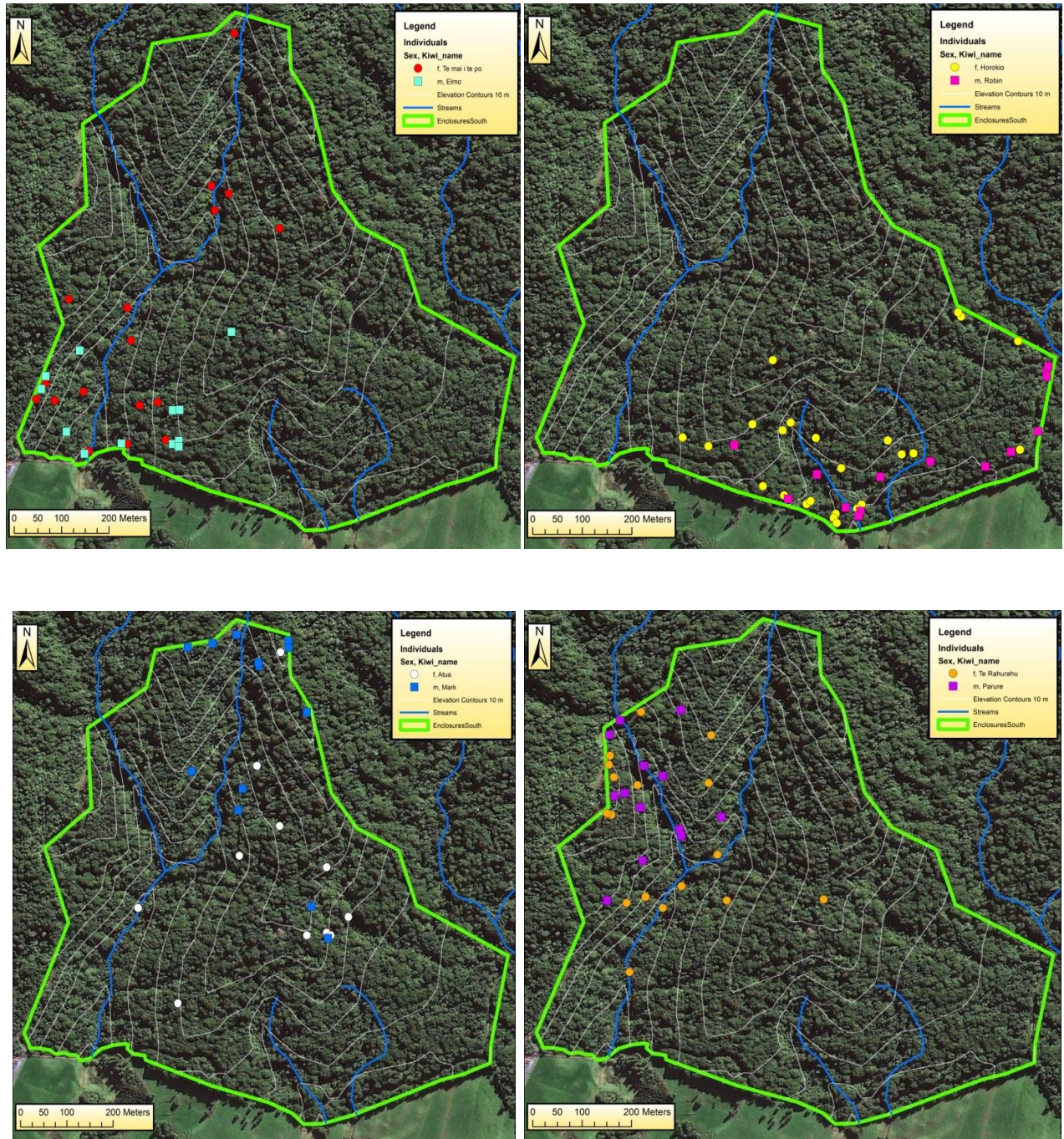
Fig.A2.U- Shelter locations of known paired kiwi in the southern enclosure

Appendix 3- Southside temperature and rain gauge data.

Date	Max deg C	Min Deg C	Rain (mm)
1-Aug-08	13.3	5	14
2-Aug-08	11.2	8.3	14
3-Aug-08	14.4	6	9
4-Aug-08	13.5	2	9
5-Aug-08	13.4	3	10
6-Aug-08	14.2	5	1
7-Aug-08	14.9	6	6.5
8-Aug-08	14.6	3	4
9-Aug-08	9.9	4	0
10-Aug-08	11.9	-2	0
11-Aug-08	13.9	1.3	18
12-Aug-08	13.6	5	17
13-Aug-08	11.6	4	12
14-Aug-08	11.4	4	20
15-Aug-08	11.2	3	26
16-Aug-08	10.2	4	13
17-Aug-08	10	0	4
18-Aug-08	13.7	2	11
19-Aug-08	13.4	-4	4
20-Aug-08	12.2	2.5	0
21-Aug-08	15.5	6.5	0
22-Aug-08	15.6	6	4
23-Aug-08	17.6	6	27
24-Aug-08	14.5	7	40
25-Aug-08	18.7	4	0
26-Aug-08	21.1	6	0
27-Aug-08	19.4	3	0
28-Aug-08	19.3	4	0
29-Aug-08	19.4	4	0
30-Aug-08	15.7	2	0
31-Aug-08	16.6	4	4
1-Sep-08	17.4	6	0
2-Sep-08	17.2	5	2
3-Sep-08	15.3	7.5	1
4-Sep-08	17.9	4	0
5-Sep-08	21.9	5	0
6-Sep-08	17.4	0	0
7-Sep-08	16.1	4	0
8-Sep-08	16.7	11.3	10

9-Sep-08	18.3	5	4
10-Sep-08	16.6	8	5
11-Sep-08	15.1	7	8
12-Sep-08	18.2	7.2	3
13-Sep-08	17.3	4	2
14-Sep-08	18.6	0	0
15-Sep-08	20.7	5	0
16-Sep-08	21.3	6	0
17-Sep-08	19.1	6	9
18-Sep-08	15.3	6	8
19-Sep-08	19.4	7.2	2
20-Sep-08	21.6	4	0
21-Sep-08	17.6	6.5	1
22-Sep-08	21.4	5	0
23-Sep-08	15.6	6	1
24-Sep-08	19.1	6	1
25-Sep-08	20.1	4	0
26-Sep-08	18.1	6	0
27-Sep-08	18.1	2	4
28-Sep-08	22.2	0	0
29-Sep-08	16.4	4.4	12
30-Sep-08	18.6	0	1
1-Oct-08	17.6	0	2
2-Oct-08	19.7	4	0
3-Oct-08	19.2	9.6	0
4-Oct-08	18.2	6	2
5-Oct-08	17.4	12	17
6-Oct-08	17	12	19
7-Oct-08	17.7	6	30
8-Oct-08	17.3	4	10
9-Oct-08	17.9	2	2
10-Oct-08	19.7	6	0
11-Oct-08	17.7	8	0
12-Oct-08	21.1	5	0
13-Oct-08	24.6	4	0
14-Oct-08	23.2	5	0
15-Oct-08	23.1	8	0
16-Oct-08	21.6	9	34
17-Oct-08	19.5	5	5
18-Oct-08	20.3	6	2
19-Oct-08	20.7	4	0
20-Oct-08	21.1	6	0
21-Oct-08	19.2	6	0
22-Oct-08	23.1	8	0
23-Oct-08	22.6	10	7.5
24-Oct-08	25.9	10	35

25-Oct-08	23.3	2	5
26-Oct-08	18.1	1	5
27-Oct-08	21.3	4	2
28-Oct-08	22.3	6	0
29-Oct-08	20.3	4	0
30-Oct-08	22.3	5	0
31-Oct-08	19.5	10	0
1-Nov-08	13.3	8	0
2-Nov-08	23.7	7	8
3-Nov-08	22.5	9.5	7
4-Nov-08	18.8	6	4.5
5-Nov-08	18.4	2	12
6-Nov-08	17.7	5	2
7-Nov-08	18.8	1.5	0
8-Nov-08	22.5	3	0
9-Nov-08	22.1	5	0
10-Nov-08	19.9	6	0
11-Nov-08	28	8	0
12-Nov-08	20.9	10	0
13-Nov-08	24.5	7	0
14-Nov-08	29.4	12.2	0
15-Nov-08	29.6	10	0
16-Nov-08	26	10	0
17-Nov-08	19.2	5	9
18-Nov-08	21.1	4	0
19-Nov-08	21.6	5	0
20-Nov-08	22.4	3	0
21-Nov-08	24.1	9.1	0
22-Nov-08	26.9	12	0
23-Nov-08	26.9	14	0
24-Nov-08	26.5	16	10
25-Nov-08	26.3	8	1
26-Nov-08	26.5	8	0
27-Nov-08	27.1	13.6	0
28-Nov-08	28.2	6	0
29-Nov-08	30	10	0
30-Nov-08	31.4	10	0
1-Dec-08	24.1	13	10
2-Dec-08	22.9	10	0
3-Dec-08	28	10	0
4-Dec-08	28	12	0
5-Dec-08	26	12	0
6-Dec-08	28	6	0
7-Dec-08	29.7	10	0
8-Dec-08	24.5	10	12
9-Dec-08	19.8	13	7

10-Dec-08	26.2	8	0
11-Dec-08	21.7	8	0
12-Dec-08	22.5	10	0
13-Dec-08	27.9	10	5.5
14-Dec-08	25.9	12	0
15-Dec-08	22.4	14	5
16-Dec-08	26.9	10	4
17-Dec-08	21.8	8	0
18-Dec-08	24.2	10	0
19-Dec-08	25.1	8	0
20-Dec-08	26	12	24
21-Dec-08	23.2	10	1
22-Dec-08	28.2	10.1	0
23-Dec-08	28.1	8	52
24-Dec-08	20.7	8.4	17
25-Dec-08	23.9	10	0
26-Dec-08	26.4	8	0
27-Dec-08	26.9	11	0
28-Dec-08	30	10	0
29-Dec-08	19.9	14	18
30-Dec-08	24.3	10	2
31-Dec-08	27.1	12	6.5
1-Jan-09	27.4	14	0
2-Jan-09	27.1	15	2
3-Jan-09			
4-Jan-09			
5-Jan-09			
6-Jan-09			
7-Jan-09			
8-Jan-09			
9-Jan-09	31.8	11	0
10-Jan-09	26.4	12	22
11-Jan-09	22.4	12	7
12-Jan-09	28.4	15.4	0
13-Jan-09	29.2	10	6
14-Jan-09	28.4	8	3
15-Jan-09	27.3	10	0
16-Jan-09	28.6	12	0
17-Jan-09	27.4	14.4	0
18-Jan-09	21.2	8	10
19-Jan-09	20.7	8	3
20-Jan-09	22	6	0
21-Jan-09	27.4	8.6	0
22-Jan-09	27.5	10	0
23-Jan-09	28.8	8	0
24-Jan-09	30.4	13.1	0

25-Jan-09	29.4	13	0
26-Jan-09	28	14	0
27-Jan-09	24.6	12	0
28-Jan-09	27.2	8	0
29-Jan-09	24.9	11	0
30-Jan-09	25.5	12	0
31-Jan-09	27.6	16	0
1-Feb-09	27.1	16.1	0
2-Feb-09	30.4	14	0
3-Feb-09	27.4	10	0
4-Feb-09	27.9	12	1
5-Feb-09	28.1	14	19
6-Feb-09	27.2	11	1
7-Feb-09	29.9	14	0
8-Feb-09	30.2	14.4	0
9-Feb-09	28.4	17.4	10
10-Feb-09	27.1	18	5
11-Feb-09	28.9	21.2	2
12-Feb-09	27.9	15.5	21
13-Feb-09	21.5	8.5	1
14-Feb-09	22.7	10	0
15-Feb-09	24.7	10.1	0
16-Feb-09	25.4	13.5	0
17-Feb-09	26.9	14.2	0
18-Feb-09	25.1	16.1	0
19-Feb-09	26.9	17.4	?
20-Feb-09	22.1	19.2	55
21-Feb-09	23.9	16.7	8
22-Feb-09	24.1	10	0
23-Feb-09	24	13.2	0
24-Feb-09	22.4	7	4
25-Feb-09	26.2	10	0
26-Feb-09	26.4	10.5	0
27-Feb-09	22.4	13.6	6
28-Feb-09	22.6	14.5	22
1-Mar-09	24	16.2	0

Appendix 4- Shelter classification tables.

Table A4.1- Individual kiwi shelter use at a detailed classification level.

Name	Exploited Root System	Downed Mass	Hollow log	Leaf Litter mound	Burrow	Fallen log	Windrow	Mamaku frond clump	Surface vegetation	Drainage pipe	Total
Cassidy	4	2				1	8				**15**
Karuwai	6	4		1		5	2				**18**
Jo	1						2				**3**
Pukupuku	1					1	4				**6**
Puke	3	4				4	4				**15**
Tari	6			2		3	6				**17**
Tuatahi	6		1		1	1	10			1	**20**
Atua	3	2		2		4					**11**
Horokio	1	3		1		5	10	1			**21**
Tae Mai	8	2		1			2	1	1		**15**
Te Rahurahu	2	5				2	4	3			**16**
Elmo	2	2		1	1	1	7				**14**
Parure	3	4	1	2	1	3	3				**17**
Robin	4				2		9				**15**
Mark	3	1			1	2	6	1			**14**
	53	29	2	10	6	32	77	6	1	1	**217**

Table A4.2- Seasonal detailed shelter usage (as a percentage) by Maungatautari kiwi.

Season	Exploited Root System	Downed Mass	Hollow log	Leaf Litter Mound	Burrow	Fallen logs	Windrow	Mamaku frond clump	Surface veg	Drainage pipe
Winter	25.0	11.8	1.5	2.9	4.4	22.1	23.5	7.4	1.5	0.0
Spring	25.8	17.7	0.0	8.1	1.6	14.5	30.6	1.6	0.0	0.0
Summer	23.4	13.0	1.3	3.9	2.6	6.5	48.1	0.0	0.0	1.3
Autumn	20.0	0.0	0.0	0.0	0.0	30.0	50.0	0.0	0.0	0.0