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Understanding Movement and Habitat Selection of the Lesser Short-tailed Bat to Infer Potential Encounters with Anticoagulant Bait

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Abstract

The lesser short-tailed bat (*Mystacina tuberculata*) and the long-tailed bat (*Chalinolobus tuberculatus*) are New Zealand's only extant endemic land-dwelling mammals. Both species are listed as nationally endangered by the IUCN, with numbers declining due to widespread habitat destruction and other human interferences. Short-tailed bats have been an unintentional victim of toxins used for pest control in New Zealand, being particularly susceptible to poisoning due to their diverse diet and ground-feeding habits. To manage toxin use to minimize bat exposure it is necessary to understand their movements and area usage behaviours.

Movements and habitat use of the short-tailed bat were studied on the area of farmland between Pikiariki and Waipapa Ecological Area, Pureora Forest Park, New Zealand. Bats using the area between the two large forests were studied using acoustic monitoring and radio telemetry techniques to determine which routes they use, how they utilise the farmland and forest fragments along the way, and how they interact with obstacles such as open farmland and roads. Evidence of foraging was more often observed near forest fragments than open areas. While levels of habitat preference varied among individuals, forest was consistently selected over open areas throughout their commutes over farmland. 50% of the radio tracked bats were commuting directly between Pikiariki and Waipapa, while a further 25% were deemed to forage or rest throughout the trip.

These results confirm that short-tailed bats utilise marginal habitats on private land, suggesting a need for the implementation of safe pest control in areas near known colonies on both public and conservation land. Stronger toxins are often used on private land so the risks to short-tailed bats could be higher. The results also provide information on how short-tailed bats make use of a fragmented environment, and whether we need to create forest bridges across open farmland to assist the nightly commute of bats.

This research was carried out under the permission of the Department of Conservation (permit number 57676-FAU) and the Massey University Animal Ethics Committee (protocol number 17/35). This was also conducted under the permission of local Iwi Te Maru o Rereahu.



Lesser short-tailed bat, Pureora Forest Park

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1 Introduction

Habitat modification is defined as the outcome of a landscape-wide alteration, a large part of which results in fragmentation, where sections of habitat are lost and remaining patches are separated from one another (Fahrig, 2003). Artificial habitat fragmentation, primarily through road building, agriculture intensification and general industrialisation, is one of the most severe threats to worldwide biodiversity (Christie et al., 2017; Rossetti et al., 2017). The loss of natural habitats can lead to changes in the ecosystem, interactions between plants and animals (Rossetti et al., 2017), and how animals can migrate or move around their territory (Morrison et al., 2016), making it more difficult for populations to thrive or behave normally. In a fragmented landscape, understanding resource selection and movement patterns of any species is therefore fundamental knowledge for effective management and conservation practices (Rechetelo et al., 2016). New Zealand is a small country which has undergone significant forest clearance for urbanisation and pasture creation, destroying the native forest habitat of many endemic species (Lloyd, 2003). One of these species is the lesser short-tailed bat (*Mystacina tuberculata*), hereafter referred to as the short-tailed bat, which was once found country-wide but is now limited to large forest patches. These bats, and other endemic species must therefore adapt to today's modified landscape, finding new ways to use the available resources.

Effects of Habitat Modification

One significant effect of fragmentation is the constraints it places on the movement of animals between habitat patches (Van Langevelde, 2015). These constraints can limit exploration opportunities and habitat choices. Habitat fragmentation through continuous human development, such as building fences, roads and other infrastructure, is a problem for animals that travel as this decreases path and foraging options. Migratory wildebeest in Tanzania have been shown to demonstrate high fidelity to particular migratory paths (Morrison et al., 2016). If this behaviour is inflexible due to memory, blocking or changing these specific routes will make it impossible, or difficult, for these animals to migrate using their preferred paths.

Animals must decide which habitats they will use, and how long they will spend there. In some cases fragmentation may create trade-offs between habitat quality and the costs of movement (Van Langevelde, 2015). A study by Sunde and Redpath (2006) on Tawny Owls (*Strix aluco*) in a fragmented landscape showed a positive correlation between the areas of open and woodland habitats in an individual's home range. Owls in highly fragmented areas compensated for the cost of having a larger home range by including as much forest habitat as possible, therefore creating a larger prey base (Sunde & Redpath, 2006). This was also seen in Kodkod cats (*Leopardus guigina*) in Chile, which increased their home range sizes in more fragmented areas to maximise prey availability (Schüttler et al., 2016). Populations of animals living in small isolated patches also show an increased sensitivity to random environmental changes, making them more susceptible to extinction (Van Langevelde, 2015). This means in fragmented landscapes, high levels of dispersal may be beneficial to population survival (Öckinger & Van Dyck, 2012). Dispersal in areas of high human activity, however, may incur large costs in terms of both mortality and energy use in most species. However, some populations show a high level of life history plasticity (Öckinger & Van Dyck, 2012). Work by Öckinger and Van Dyck (2012) on the speckled wood butterfly revealed habitat finding ability in fragmented landscapes to be a heritable trait. Butterflies that originated from fragmented landscapes were more efficient at finding habitat compared to individuals from a homogenous landscape. This suggests that adaptations which reduce dispersal costs might help compensate for the negative effects of fragmentation in organisms with short generation times (Öckinger & Van Dyck, 2012).

Not all animals experience equally negative effects of habitat fragmentation. Some species may be limited to the habitats which they can utilise, resulting in isolated populations (Row et al., 2012). This can be detrimental not only for resource availability, but also genetic diversity (Melosik et al., 2016). Other species can show some level of plasticity, and modify habitat use patterns (Öckinger & Van Dyck, 2012; Row et al., 2012). For example, some species of frogs and butterflies can colonise previously unreachable habitats providing more available habitat area. Some aerial insectivores, such as birds, make use of fragmented habitats by feeding on the high abundance of insects found around forest edges (Bereczki et al., 2015).

Another form of habitat modification is the application of toxins for conservation purposes. Conservation organisations worldwide commonly use a range of traps and toxins

such as anticoagulants to maintain populations of introduced mammalian predators such as the possum (*Trichosurus Vulpecula*), and the ship rat (*Rattus rattus*) (Eason & Wickstrom, 2001; Robertson et al., 2017). While pest control methods aim to eradicate or control introduced predators, it may also have a detrimental effect on the native populations we are trying to protect (Hoare & Hare, 2006; Dennis & Gartrell, 2015; Morriss et al., 2016). Unintentional by-kill of other species is a common consequence of conservational pest control methods. 1080 (sodium fluoroacetate) is a widely used toxin, distributed over large areas in pellets, or a (historically) paste (Eason & Wickstrom, 2001). Before distribution, bird repellent is added, and pellets are screened to remove small pieces which may be picked up by smaller birds and mammals (Eason & Wickstrom, 2001). It has been seen that after aerial distribution of 1080 in New Zealand, tree foliage and fruit production increased, and total bird populations and large invertebrates appeared to benefit (Byrom et al., 2016). Evidence of high mortality in native bird species in the 1980s prompted the Department of Conservation to change their methods of baiting practices making it more unattractive to avian species (Morriss et al., 2016). Modifications to baiting procedure and ingredients can affect the risk of harm to birds and other non-target species (Morriss et al., 2016). Of the dead blackbirds (*Turdus merula*) found and tested between 2003 and 2014, 96% contained residues of 1080 (Morriss et al., 2016). Alternative bait laying methods, such as strip or cluster sowing, have been seen to significantly reduce the levels of inadvertent by-kill in birds and non-pest species (Morriss et al., 2016).

In some areas of New Zealand mammalian pests are being managed using the anticoagulant brodifacoum (Hoare & Hare, 2006). It has been used in New Zealand since the 1990s, via aerial distribution on islands and (in exceptional circumstances, due to its timely environmental persistence) bait stations on the mainland (Eason & Wickstrom, 2001). In terms of how brodifacoum affects non-target species, birds and their invertebrate prey are the most commonly studied. The most severe case of non-target species mortality was in 1978, where brodifacoum bait stations killed the entire population of weka (*Gallirallus australis*) on Tawhitinui Island in the Marlborough sounds (Taylor, 1984; Hoare & Hare, 2006). Under the correct practices predator management systems can be effective in helping to preserve a species at the population level (O'Donnell & Hoare, 2012). However, if not enough information is known about the surrounding non-target species huge mortality can occur

(Hoare & Hare, 2006). When modifying the habitat for conservation purposes it is important to understand how all aspects of the ecosystem function, allowing for the development of educated risk management. To avoid unnecessary by-kill when considering toxin placement and distribution it is important to understand how individuals interact with and move around their environment, particularly in fragmented habitats where an animal's ability to move freely may be compromised.

Measuring Animal Movements

The way in which animals interact with, and move around, their habitat can be measured using many chemical, physical, or telemetric methods, all of which have different uses and levels of usefulness. Movement patterns on large scales such as migration can be predicted through methods involving biochemical analysis. Ethier et al. (2014) found that American badgers' migration origins could be determined using element variability in the claw keratin, as the soil properties of their habitat differed between pre and post migration. This method of studying geographical movement has many restrictions. For example, it would not be useful for measuring short distance movements where the animal is not traveling to an area with different soil properties. It is useful, however, for animals like badgers, which are difficult to study using other methods due to their low population densities, and tendencies to hide.

A more common method used to investigate animal movements is mark-recapture, where an animal is fitted with a mark or device that allows it to be identified later. While it is possible to use unique natural markings for animal identification (Morrison et al., 2016), it is more common for humans to put marks or devices on animals. This can be done through use of bands, where animals could be fitted with a series of different number or colour combinations to differentiate individuals. This method is used because it is easier, and less disruptive, to observe and identify an individual from a distance than to catch it and read a numbered tag (Conn et al., 2004). While banding is commonly used on legs of birds (Barker et al., 2005; Hurley et al., 2013) it can also be applied to other species such as neck bands on lizards (Ribeiro & Sousa, 2006), and forearm bands on bats (Esbérard et al., 2017).

A PIT (Passive Integrated Transponder) tag is a small electronic chip that contains a unique identity code (Boatman et al., 1998; Gibbons & Andrews, 2004). PIT tags are

permanent, and providing they do not interfere with normal activities, have no detrimental effect on the individual (Gibbons & Andrews, 2004). These chips are injected into animals, allowing individual identification (Gibbons & Andrews, 2004). This way animals can be scanned at different locations and their movement patterns interpreted (Gibbons & Andrews, 2004). Work on arboreal marsupials in Australia used PIT tags to analyse the usefulness of canopy bridges which were constructed over a freeway to minimise the effects of habitat fragmentation (Soanes et al., 2015). PIT tag readers were placed on canopy bridges in a way that detected tagged animals as they used the structures. Through this technology it was possible to determine that these bridges were regularly used by many species, and provided safe access to otherwise unreachable resources in a fragmented habitat (Soanes et al., 2015). Detection of PIT tags with antenna arrays can be used as a less distressing alternative to other mark-recapture methods, as it minimises the level of animal handling required (Pearson et al., 2016).

Radio telemetry takes movement tracking one step further through GPS (Global Positioning System) or VHF (Very High Frequency) transmitter tracking. Individuals can be fitted with transmitters that release signals at a particular frequency which can be tracked by VHF receivers tuned to the appropriate incidence (Laskowski et al., 2016). This allows animals to be tracked to assess exactly how they are moving and using their environments. GPS technology allows researchers to track animals digitally, and automatically. While GPS tracking of large animals such as wildebeest (Morrison et al., 2016) has been readily available for some time, advances in miniaturisation technology is allowing increasingly smaller animals, such as the Tasmanian devil (*Sarcophilus harrisii*) to be GPS tracked (Thalmann et al., 2016).

Habitat Use in New Zealand Bats

Bats are nocturnal mammals with webbed forelimbs, making them the only mammals with the capability of carrying out powered flight (Hunter, 2007). Habitat use of forest dwelling bats depends on many variables, such as environmental conditions, prey availability, abundance of obstacles, and population size (Luszcz & Barclay, 2016). The lesser short-tailed bat (*M. tuberculata*) and the long-tailed bat (*Chalinolobus tuberculatus*) are New Zealand's

only extant endemic land-dwelling mammals, and species of bat. Both species are listed as nationally endangered by ICUN, with numbers declining due to widespread habitat destruction and other human interferences. Long-tailed bats are aerial insectivores that forage along forest edges throughout the night, before returning to roosts in old forest trees (O'Donnell et al., 2006), whereas short-tailed bats are more commonly found in large areas of mature indigenous forest. A study by O'Donnell et. al. (2006) revealed little overlap in the foraging habitat of these two bat species. Long-tailed bats preferred to hunt in open spaces such as forest edges, and artificial corridors created by road construction, before returning into the forest to roost. The short-tailed bat, however, tended to avoid open areas, sticking to the shelter of large forest areas. A higher level of activity was measured in areas closer to communal roosts.

These two species of New Zealand bat occupy different niches. long-tailed bats are purely aerial insectivores (Gurau, 2014) and strong fliers. However, wing morphology restricts manoeuvrability in dense vegetation (O'Donnell, 2001). Due to this, long-tailed bats hunt in open areas on the forest edge where there is suitable space to fly (O'Donnell et al., 2006). Roads may even provide these bats with open corridors in which use of echolocation to find insect prey is not disrupted by obstacles (O'Donnell et al., 2006). Short-tailed bats are omnivorous, eating arthropods, fruit, pollen and nectar (Daniel, 1979; Jones et al., 2003). The wing morphology of these bats allows them to easily manoeuvre in small spaces, and take off from a flat surface (Lloyd, 2001). It is not specialised for any one flight strategy, which likely reflects the large range of foraging methods used by the short-tailed bat (Lloyd, 2001). Short-tailed bats spend 30% of their foraging time searching for food on the forest floor, crawling and even burrowing in search of food (Riskin et al., 2006). While not flying, they are able to move around with quadrupedal locomotion by folding their wings around their forearms and using them as legs (Daniel, 1979). This is a trait seen also only in the common vampire bat *Desmodus rotundus* (Riskin et al., 2006). The short-tailed bat is New Zealand's only surviving endemic mammalian pollinator, and has formed an important mutualistic relationship with *Dactylanthus taylorii*, an endemic ground flowering plant (Ecroyd, 1996; Cummings et al., 2014). This is the only bat-pollinated ground flowering plant in the world, and the only endemic plant which has evolved to promote bat visitations (Cummings et al., 2014). This flexibility in foraging strategies allows individuals to forage throughout the night without

constraints in the abundance of flying insects (Christie, 2006). While aerial insects are located through echolocation, it is likely the bats use aural, olfaction and tactile cues to locate food sources when crawling around (Jones et al., 2003).

Effects of Habitat Modification on New Zealand Short-Tailed Bats

The mutualistic relationship between short-tailed bats and *D. taylorii*, and their diverse foraging strategies make short-tailed bats one of the most ecologically important species in the forest ecosystem (Toth et al., 2015a). Despite this, little research has been done on how bats respond to the habitat loss and fragmentation which has occurred in New Zealand since British colonisation. Historical and fossil evidence suggest the species was once widespread but has become extinct in many areas due to forest clearance (Lloyd, 2001, 2003). It is currently found at only a few sites, scattered around New Zealand. This is not only a problem for the bats, but also for other native wildlife. As seen in other ecosystems, a reduction in the numbers of local pollinators has a negative effect on the plants which they pollinate. Local extinctions of the short-tailed bat due to declines in range and population size has resulted in decreased pollination of *D. taylorii*, and therefore a less available food source (Cummings et al., 2014).

In New Zealand's fragmented landscape, short-tailed bats have had to adjust to alternative habitats, and have been detected utilising areas outside of native forests, in both pine plantations (Borkin & Parsons, 2010) and open pasture (Toth et al., 2015a). Bats can be sensed using detectors which record noises at specific frequencies. Due to differences in short-tailed and long-tailed bat vocalisations, the two species can be differentiated (Parsons, 2001). Bat detectors can be used to determine the presence or absence of bats in a particular areas, but cannot easily differentiate between individuals (Parsons, 2001). While short-tailed bats are too small for attachment of current GPS tracking technology, lightweight transmitters can be used with receivers to detect their movement patterns (Christie & O'Donnell, 2014; Toth et al., 2015a). Using radio transmitters, Toth et al. (2015a) successfully tracked 18 individuals in an area with patches of native forest, exotic plantation, pastoral land and harvested forest. They found that while bats preferred, and roosted in, native forest, some individuals foraged in exotic pine plantations almost exclusively. This was the first

demonstration of habitat use plasticity in a species believed to be an obligatory forest dweller (Toth et al., 2015a). Short-tailed bats were seen to spend time in exotic pine plantations which neighbour native forests, but it is unknown how these areas are actually used by the bats (Borkin & Parsons, 2010). These individuals will usually return to their roost deep in the native forest before sunrise (Borkin & Parsons, 2010; Toth et al., 2015a), so it is suggested they use plantations to forage (Dennis, unpublished data, 2010). Very little research effort has been put into determining how the short-tailed bat travels between neighbouring forest fragments, i.e. whether they use any available corridors of vegetation cover or are willing to fly directly over open pastoral areas. The chosen movement patterns could have a significant effect on the wellbeing of the species, as previous studies have found a preference for predators to make use of habitat corridors as a method of ambush (Hastie et al., 2016).

Short-tailed bats have been an unintentional victim of toxins used for pest control in New Zealand (Daniel & Williams, 1984; Dennis & Gartrell, 2015). While introduced mammalian predators themselves are a threat to bats, the bats are also susceptible to toxins due to their diverse diet and ground feeding habits (O'Donnell et al., 2011). Previous studies have shown evidence of leaf litter arthropods feeding on baits, which creates a risk of secondary poisoning through ingestion of these insects (Lloyd & McQueen, 2000). Lloyd and McQueen (2000) studied the concentrations of 1080 in forest arthropods, and concluded short-tailed bats need only consume 0.04 g (0.7% of their daily intake) of poisoned insects to receive a lethal dose (Lloyd & McQueen, 2000).

Pureora forest park is a conserved forest area located in the central North Island of New Zealand, home to a single known colony of short-tailed bats. In 2008, to control the numbers of introduced predators, the toxin diphacinone was dispensed as a paste, in plastic bags hanging from trees (Dennis & Gartrell, 2015). During this baiting period, 115 short-tailed bats were found dead, or dying, at the bases of maternity and colonial roost trees, with evidence of diphacinone in 10 of the 12 liver samples tested (Dennis & Gartrell, 2015). This led to reassessment of toxin use in Pikiariki Ecological Area, the forest surrounding colonial roosts, and diphacinone was distributed as hard pellets housed in bait stations. These are placed early in the season while bats are least active to decrease the chances of causing bat mortality (Dennis, 2015). Two kilometres north of Pikiariki, separated by open pasture and a state highway is Waipapa Ecological Area, which some short-tailed bats have been

documented to visit during foraging hours (Toth et al., 2015a). Pest control methods in Waipapa consists of aerial 1080 and pellet anticoagulants, for which the timings of deployment have not been modified to minimise the effect on non-target short-tailed bats (Department of Conservation, 2016). To travel between these two areas, short-tailed bats must navigate through small patches of fragmented forest, or open farmland.

Thesis Outline

For this project I studied the movements and habitat use of the short-tailed bat on the farmland area between Pikiariki and Waipapa, at Pureora Forest Park, New Zealand (Figure 1.1). To manage toxin use and minimize bat exposure it is necessary to understand their

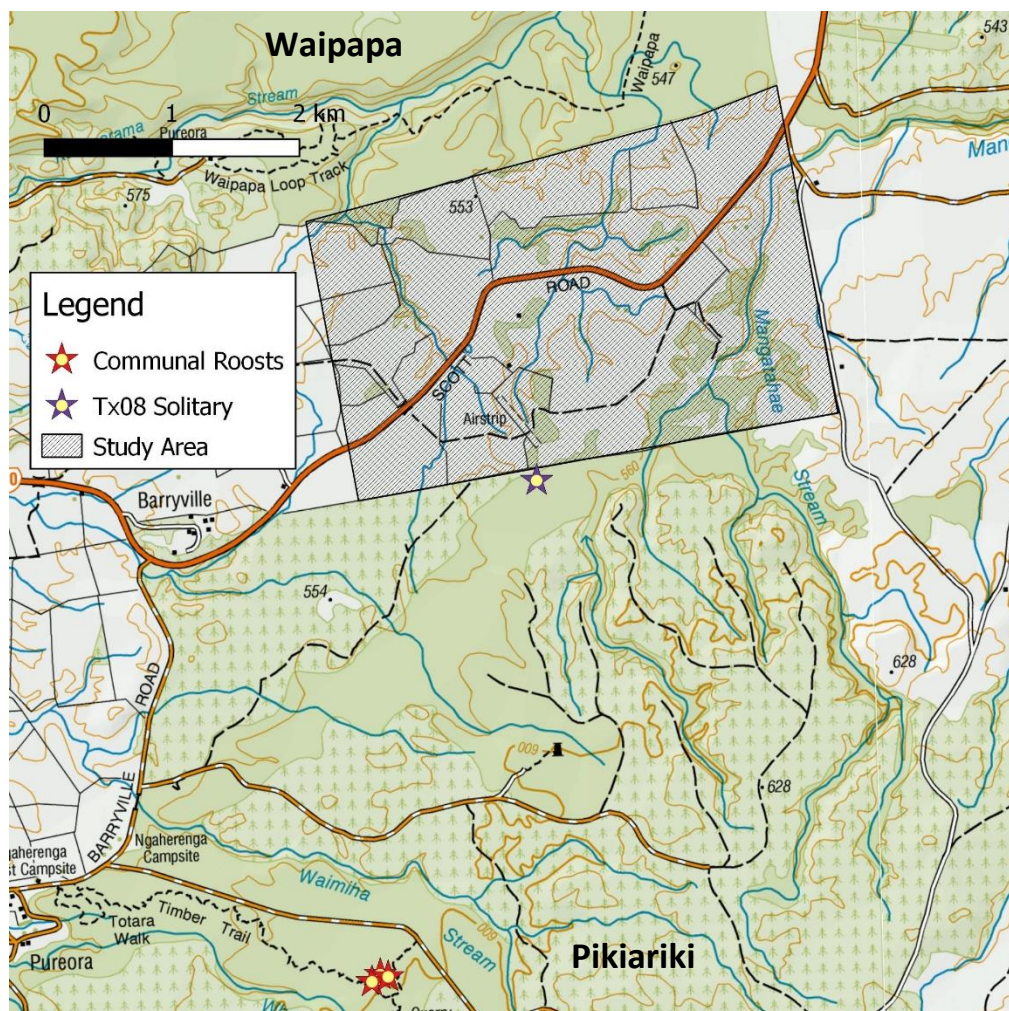


Figure 1.1: Pikiariki Ecological area and South Waipapa, in the Central North Island, New Zealand (-38.4805, 175.5875), showing known communal roosts and one solitary roost relevant to the study. The area which was surveyed is highlighted in grey. Green areas represent native and exotic forests, and light grey show open agricultural areas.

movements in this fragmented landscape. I therefore assess the area usage of bats crossing between the two forest patches, which routes they use, and how they utilise the farmland and forest fragments along the way. This initially involved setting up a series of bat recorders (unidirectional digital Bat Boxes, Version B4 contained in a waterproof 'OtterBox 2000 series', Department of Conservation Electronics Workshop, Wellington, New Zealand); and omnidirectional AR4 devices (Department of Conservation Electronics Workshop, Wellington, New Zealand) between these two sites to determine the most common areas that the bats cross. Bats were then tagged with transmitters and tracked to determine their travel paths and how they interacted with obstacles such as open farmland and the main road. This also provided information on which demographics of bat are making these journeys, and what they are doing along the way. DOC will be provided with information on the need to alter pest control timings and bait placement in Waipapa to reduce the level of inadvertent toxicity. It also provides information on how short-tailed bats make use of a fragmented environment, and whether we need to be encouraging forest bridges across open farmland to assist the nightly commute of short-tailed bats.

The research was divided into two parts. Chapter 2 describes how acoustic monitoring arrays can be used to speculate about bat activity through presence or absence analysis. The information obtained expands on a previous small-scale monitoring project carried out by the New Zealand Department of Conservation in the same area to investigate the possibility of short-tailed bats using the landscape as a means of travel. The aim of this chapter was to expand on this previous knowledge in order to determine the most efficient way to proceed with methods in Chapter 3.

Chapter 3 specifically focusses on habitat selection and area use in a fragmented environment through the use of transmitters and radio telemetry. I assessed preference for specific habitats within a defined area and hypothesised uses of the area, as well as the demographics of individuals present.

Chapter 4 provides a synthesis of the results and brings them into a conservation context by providing a short report for the Department of Conservation. I conclude with some recommendations.

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2 Passive Acoustic Monitoring of Area Usage

Introduction:

Traditional wildlife monitoring focused on physical observations of individuals or signs of their presence. However, advancements in recording technology have allowed the development of passive acoustic monitoring. This is a method commonly used by ecologists to carry out surveys for questions involving abundance (Efford et al., 2009), activity levels (Xie et al., 2016), or assessing the effects of large or small scale environmental changes (Deichmann et al., 2017). It involves setting out recorders over a study area and using vocalisation to determine species presence. Recent research on forest elephants (*Loxodonta cyclotis*) has highlighted the diversity of applications of acoustic monitoring, including mapping diversity and movement patterns which can assist in determining the efficacy of conservation efforts (Wrege et al., 2017). The implementation of acoustic monitoring enhances the amount of data that can be collected and the area covered, while reducing the need for numerous field researchers and therefore reducing observation bias (Steer, 2010). Results obtained from acoustics recordings can be cross-verified by experts, removing the risk of species being wrongly identified by inexperienced observers (Steer, 2010). Acoustic monitoring also provides an unobtrusive method of presence or absence analysis, making it suitable for rare, sensitive or cryptic (shy or nocturnal) animals such as the short-tailed bat and the long-tailed bat of New Zealand.

While both species of New Zealand bats make vocalisations that are audible to humans (O'Donnell et al., 1999; Toth et al., 2015b), the high frequency vocalisations they produce during echolocation are the most useful for monitoring. Echolocation is used by some animals to navigate under poor light conditions. It utilises the fact that solid surfaces reflect sound, as animals that produce high frequency vocal clicks can interpret the delay in returning soundwaves after they bounce off surrounding objects (Panyutina et al., 2017). Direction is determined by comparing the relative intensity of signals received in each ear, providing information on the angle at which reflected waves arrive (Kay, 1962; Jones & Teeling, 2006). Ultrasonic echolocation is used by several groups of mammals including shrews and cetaceans (Frasier et al., 2017; Panyutina et al., 2017), and its use in bats was first

demonstrated by Griffin (1958). The echolocation behaviour of bats provides an opportunity for acoustic recording utilising the high frequencies produced (Adams et al., 2012). It is used by all 1000 species of microchiroptera (Ratcliffe & Jakobsen, 2018) and the megachiropteran genus *Rousettus* (Jones, 1999).

The objective of this study was to build on the previous knowledge of short- and long-tailed bat activity in the farmland area surrounding Pikiariki Ecological Area at Pureora Forest Park by setting out an array of ultrasonic sound monitors. To develop efficient species management plans that minimize accidental bat exposure to nearby toxins used in pest control it is necessary to understand their movements in the fragmented landscape. This initially involves setting up an array of bat detectors to determine the highest areas of bat activity. This research repeats, in greater detail, an unpublished pilot study performed by University of Waikato and the Department of Conservation in 2016 that suggested the presence of both species of New Zealand bat in the farmland area (Parker, 2016). Acoustic monitoring arrays can be used to speculate about bat activity through presence or absence analysis, additional knowledge which provides insight into hotspots of bat activity. This information is essential for further research requiring bat capture away from roost entrances or out in the open, such as the habitat selection analysis described in chapter 3. The results confirm the presence of both short-tailed and long-tailed bats, and identify areas of high and low passes. Using density maps of recorded passes inferences can be made about possible reasons for bats using the farm and surrounding areas, which may have implications for the methods of pest control used in the surrounding areas. Due to limitations of acoustic monitoring equipment, more detailed information on area use such as individual flight paths and habitat use was carried out as further research described in Chapter 3.

Methods:



Figure 2.1: Examples of the automatic bat monitors (ABM) which were used in this study. A) unidirectional digital Bat Boxes (Version B4 contained in a waterproof 'OtterBox 2000 series', Department of Conservation Electronics Workshop, Wellington, New Zealand). B) Omnidirectional AR4 devices (Department of Conservation Electronics Workshop, Wellington, New Zealand)

Automatic Bat Monitors

Due to last minute loss of equipment, two types of Automatic Bat Monitor (ABM) were used: digital Bat Boxes (Version B4 contained in a waterproof 'OtterBox 2000 series', Department of Conservation Electronics Workshop, Wellington, New Zealand), and omnidirectional AR4 devices (Department of Conservation Electronics Workshop, Wellington, New Zealand) (Figure 2.1). OtterBox ABMs can record sound from all angles but tend to record passes at nearly twice the distance if the bat is directly in front (O'Donnell & Sedgeley, 1994). Similarly, while the AR4 devices were designed to be more omnidirectional, objects such as trees and fenceposts (seen in Figure 2.1) can affect bat detection. Both devices detect ultrasonic waves of bat echolocation and convert them into viewable formats. The Bat Boxes record two channels (28 and 40 KHz), so differentiates species (see below), and saves the data as WAV audio files. The AR4 devices convert sound into a bitmap image of a compressed spectrogram. Both devices are triggered, meaning they only turn on after detecting sound within ultrasonic frequency range. Sound and image files were viewed and analysed in BatSearch and BatSearch3.12 respectively (Department of Conservation, New Zealand). Short-tailed and long-tailed bats can be distinguished by their call frequencies. Long-tailed bats have a peak

call at about 40KHz, and short-tailed bats have two harmonics at about 28 and 48KHz (Parsons, 1997) (figure 2.2). Echolocation clicks from long-tailed bats are generally spaced further apart than those of *M. tuberculata* but there is a degree of variation due to environmental conditions, surrounding objects, the specific activity being performed, and individual characteristics (Stathopoulos et al., 2018).

The 33 ABMs used were initially time synched and tested for one night close to known communal bat roosts in the Pikiariki Ecological Area. They were set out systematically over a one-month period (19 September till 19 October 2017) activating nightly between 7 pm and 6 am, resulting in a total of 225 unique monitoring locations and 7425 hours of recorded activity. The landscape was divided into 10 sample areas, each monitored with a subset of the 33 recorders placed within 50-100 m from its nearest neighbour to account for detector ranges (figure 2.3). ABM's were left for a minimum of 3 nights in each sample area before being collected to clear SD cards, resynchronise clocks, and relocated to the next set of locations. Placements were generally restricted to locations with trees or a fence line and limited by topological features such as stream gullies.

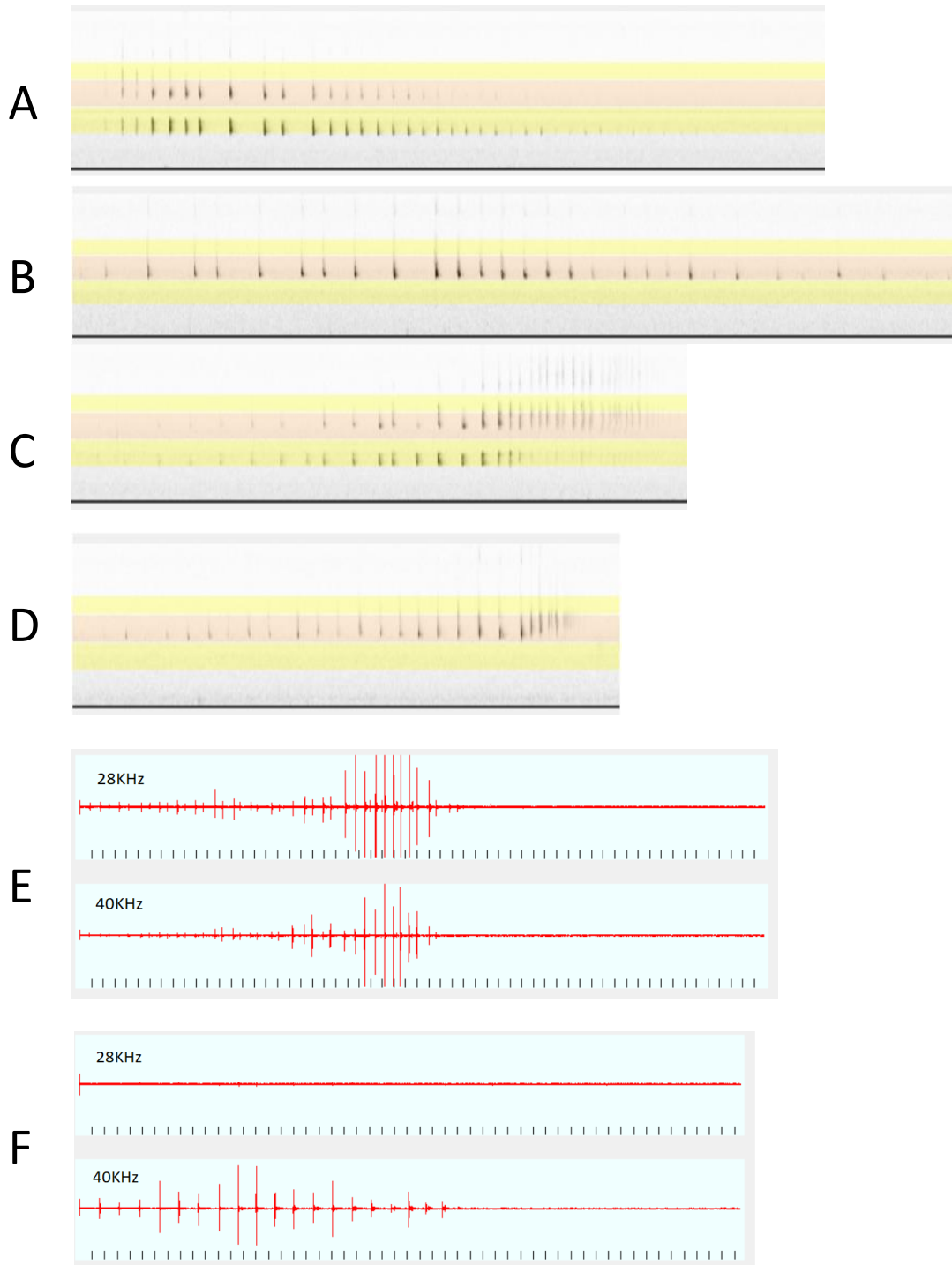


Figure 2.2: Echolocation clicks of short-tailed and long-tailed bats from two models of ABM. A) Compressed spectrogram images of commuting clicks from a short-tailed bat showing regular bands at two frequencies, 28 and 48KHz, recorded on an AR4 device. B) Compressed spectrogram images of commuting clicks from a long-tailed bat showing regular bands at 40KHz, recorded on an AR4 device. C and D) Compressed spectrogram images of a feeding buzz from a short-tailed and a long-tailed bat respectively, showing more rapid clicks slightly increasing in frequency as the bat catches insect prey. This pattern is typical of a bat feeding echolocation (Wright et al., 2013). E) Waveform output of a short-tailed bat pass showing signal on both the 28KHz and 40KHz channels recorded on a Bat Box. F) Waveform output of a long-tailed bat pass showing signal on only the 40KHz channel recorded on a Bat Box.

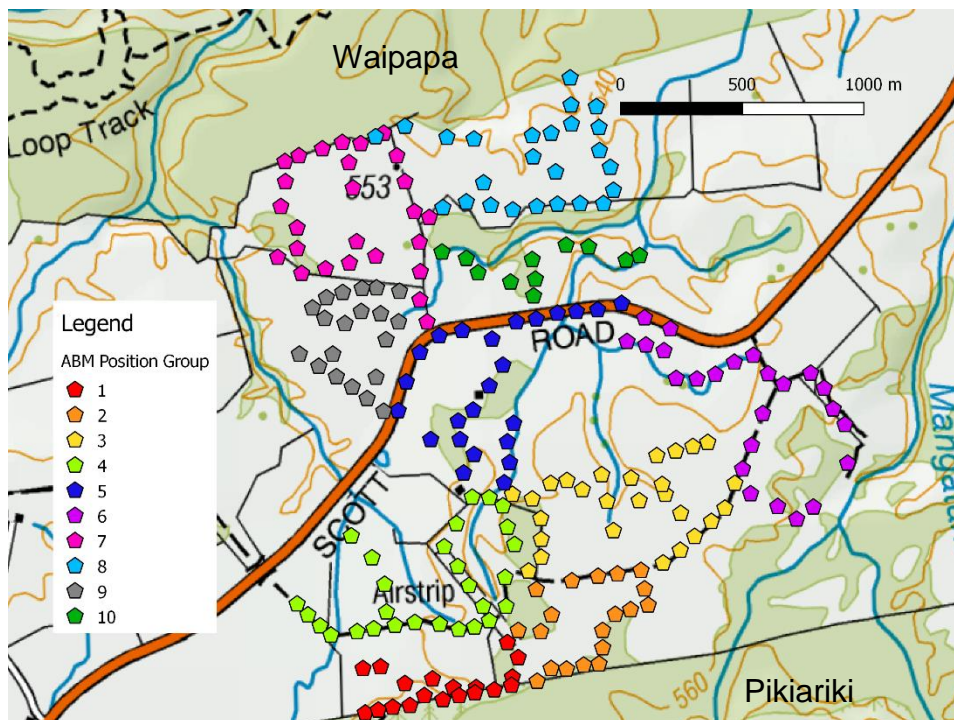


Figure 2.3: All 225 Automatic Bat Monitor locations separated into 10 groups according to the dates that data were collected on, between Pikiariki Ecological Area and Waipapa Forest (-38.4805, 175.5875). Light green and grey areas indicate native forest cover and pasture respectively. Blue lines represent streams.

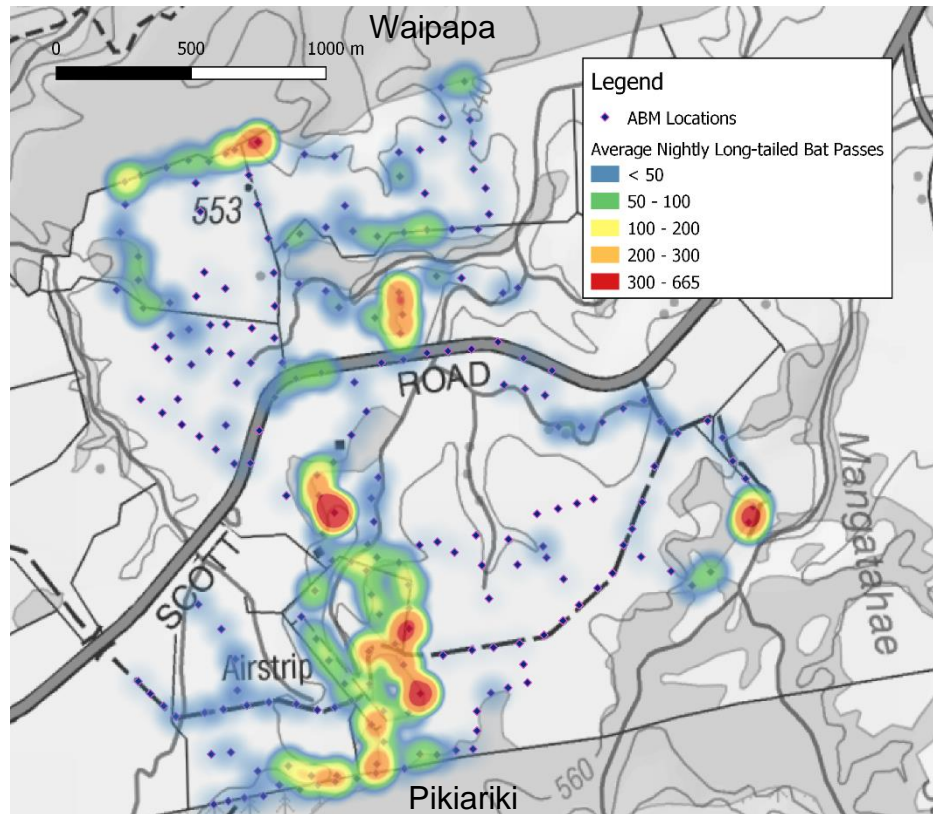
Data Analysis

Sound and image files from each night were manually scanned for presence or absence of bat calls, which of the two species the calls came from, and whether they showed evidence of a signature feeding buzz (figure 2.2). These data were entered into QGIS 2.18 for visualisation and manipulation. Average nightly passes for each species were used to create heatmaps revealing areas of high and low activity and overlaid onto area maps to compare activity with habitat type. Each surveyed position was assessed for evidence of feeding buzzes and marked if at least one was detected over the entire 3-night period. This begins to reveal bats might be utilising the area.

Results:

In total the ABM's detected 2280 short-tailed bat and 30297 long-tailed bat passes. An average of 10.1 short-tailed bat passes were recorded over the three nights at the 225 locations, compared to an average of 134.7 passes for long-tailed bats (Two Sample t-test, p

A



B

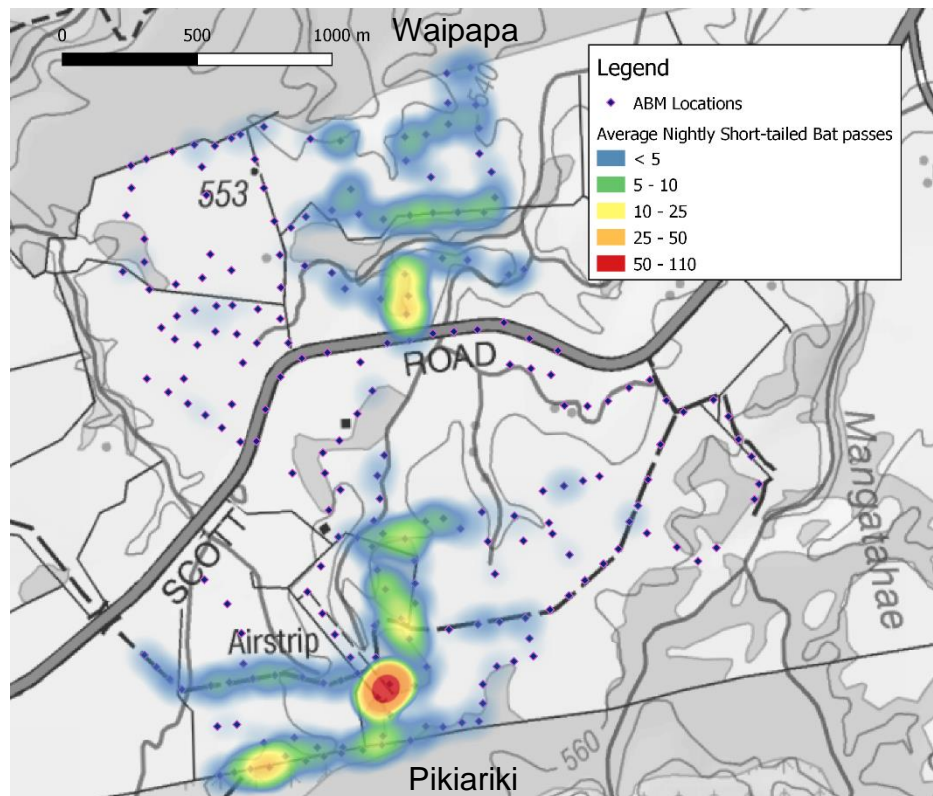


Figure 2.4: Average nightly passes over three nights for (A) long-tailed bats (LTB) and (B) short-tailed bats (STB) with a point diameter of 100 m, and all ABM locations, created on QGIS 2.18. Light grey areas represent forest cover while white shows open pasture.

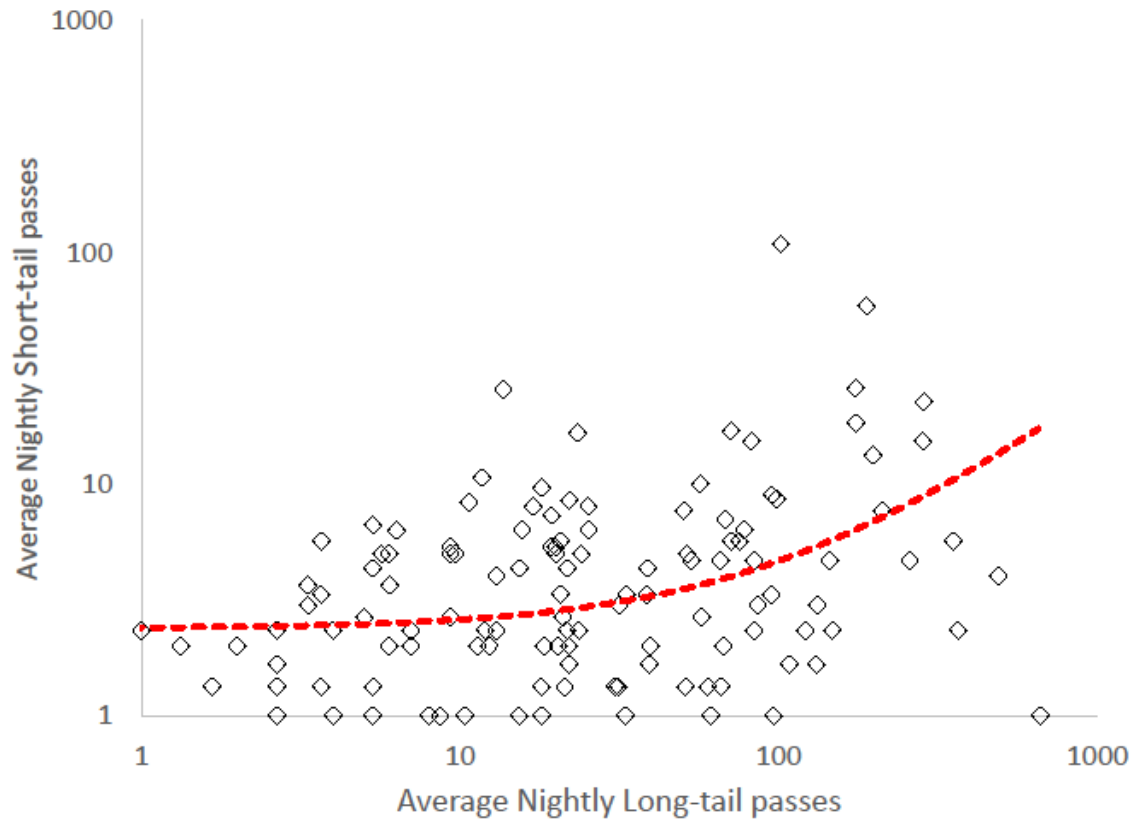
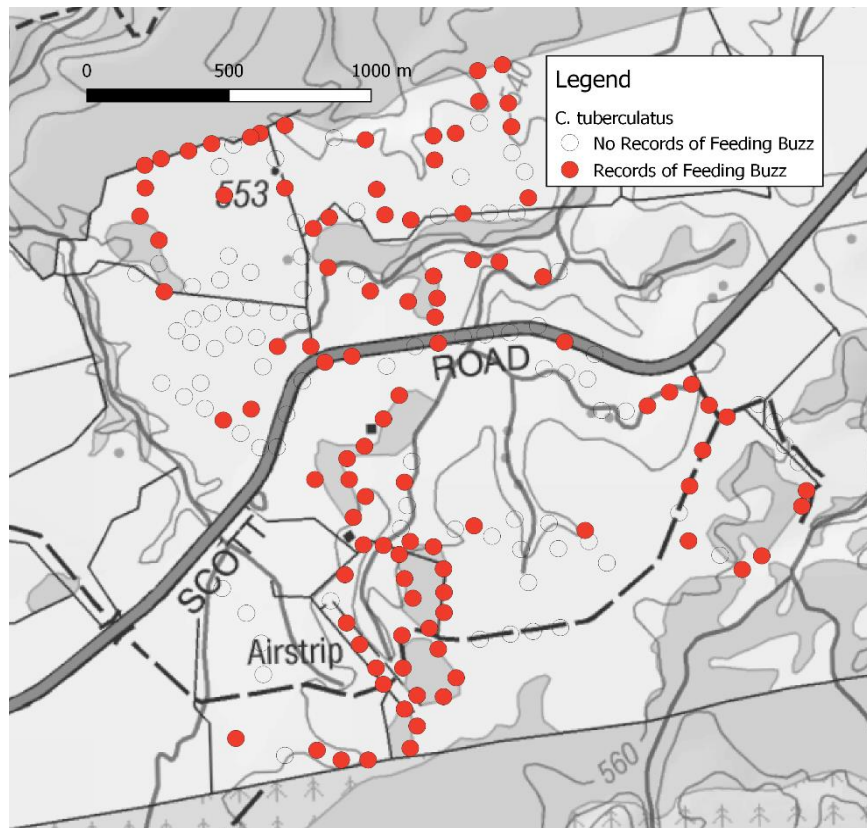


Figure 2.5: Scatter plot showing the correlation between average nightly both short-tailed bat and long-tailed bat passes with a log scale. Due to the difference in overall numbers of passes between the two species, plotting the data on a log vs log graph removes emphasis on larger numbers. No linear trend is apparent, with an R^2 value of 0.0517. In general, the number of bat passes is high at the same locations between both species, however there is a large variation between positions resulting in low predictability.

< 0.001). About 44% of locations (100/225) recorded an average of < 1 short-tailed bat passes per night, whereas only 6% (13/225) recorded <1 long-tailed bat pass per night. Both species were recorded most frequently close to forest fragments, but long-tailed bats more commonly passed through open areas (Figure 2.4). There was no clear correlation between the average number of passes from each species (Figure 2.5). Hotspot areas of long-tailed bat passes can be seen throughout the entire farmland area, but there is a clear gap in short-tail passes in the central area of the farmland (Figure 2.4). In both species, it was more likely to see evidence of foraging near forest fragments than in open areas (Figure 2.6).

A



B

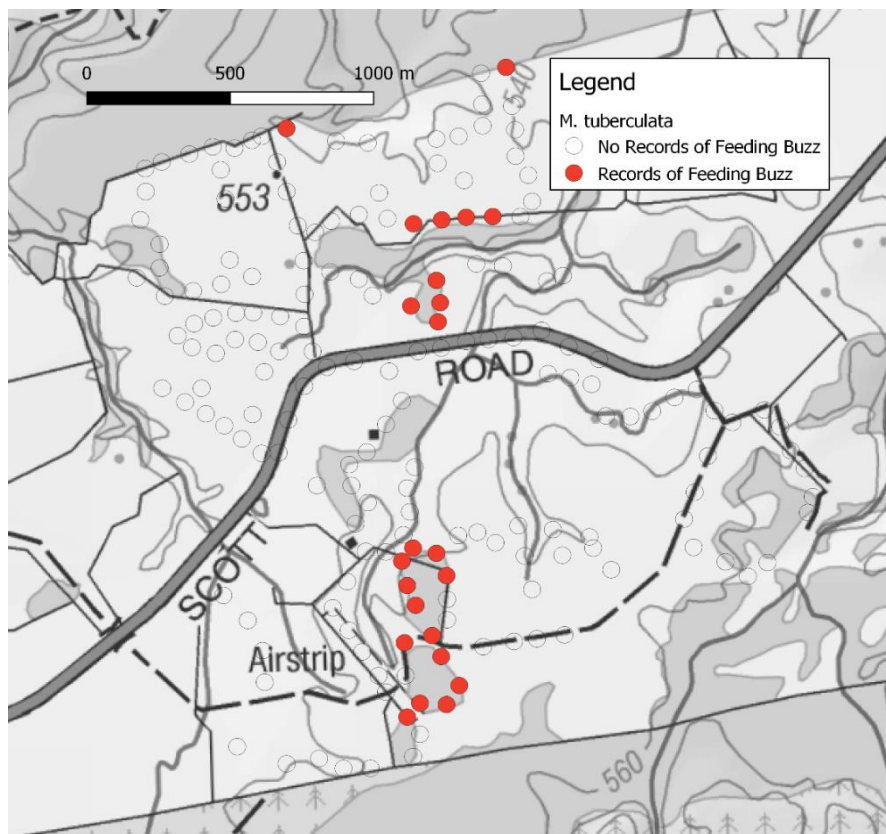


Figure 2.6: Evidence of foraging activity in the study area. Red dots represent locations where feeding buzzes were recorded, and white dots where they were absent for (A) long-tailed bats and (B) short-tailed bats. Light grey areas represent forest cover while white shows open pasture.

Discussion:

The results clearly support the suggestion that both bat species can be found using this area of farmland between Pikiariki Ecological area and Waipapa Ecological Area. The most prominent hotspots for both species occur near the fragmented forest corridor which runs through the farm, consistent with the idea that these species are obligate forest dwelling bats (Toth et al., 2015a). With acoustic monitoring alone, it is impossible to determine whether this was a result of a preferred direct flight path for many individuals, or an area where a few individuals spent a large proportion of time due to higher food availability. Examples of commuting clicks and feeding buzz were observed in both open and forested areas. Locations which recorded at least one example of a feeding buzz were marked, but many ambiguous call structures made further analysis (such as looking at the frequency of feeding buzzes at different locations) difficult. As a bat crosses through different habitat types it can alter its echolocation structure to best suit the new area, which leads to huge variation in call shape (Lloyd, 2001; Russo & Voigt, 2016). It must also be noted that the absence of feeding buzzes from data records does not necessarily mean bats were not foraging in the area (O'Donnell et al., 2006). The echolocation calls of short-tailed bats are a relatively low amplitude making them harder to pick up, and feeding echolocations are often missed in other species of bat with similar call structures. It is also possible that within forest fragments bats were spending time foraging under leaf litter using olfaction rather than echolocation to detect prey (Jones et al., 2003) which would not be picked up by the monitors.

While hotspots of frequent bat passes are in similar areas for the two species there are few other similarities in short-tail and long-tail bat habitat use distributions. There were significantly more long-tailed bat passes recorded over the entire area, particularly in open areas, both in total count and the number of positions with less than one nightly pass. More passes is likely to mean a higher overall abundance, although it is also possible that long-tailed bats just spend more time passing back and forward through the area. There is also little correlation between the number of passes at each site between the two species. This finding is consistent with comparisons by O'Donnell et al. (2006) at Eglinton Valley in the Fiordland National Park New Zealand. They reported that 15.7% of long-tailed bat passes were in open grassland areas, compared to only 0.2% of short-tailed passes. They also found that short-tailed bats were most likely to be found more than 200 m into the edges of mature native

forests, whereas long-tailed bats were most abundant at forest edges. Most bat species prefer edge habitats to open fields (O'Donnell et al., 2006; Wolcott & Vulinec, 2012), presumably as a compromise between the increased insect prey in agricultural areas, and the physical protection provided by tree cover (Wolcott & Vulinec, 2012). Short-tailed bat passes were not recorded in a gap in the centre of the study area, which is not apparent in the long-tailed bat data nor the Department of Conservation's preliminary study of both species from the previous year (Parker, 2016). This gap may be the result of one of three reasons:

1. Waipapa and Pikiariki Ecological Areas host two distinct groups of short-tailed bat, each which forage on farmland areas adjacent to their home habitat but rarely cross larger gaps of open fields between the two forests.
2. Short-tailed bats were crossing between these two forest areas at an unmonitored area of farm outside of defined study area.
3. Short-tailed bats were crossing the entire farm area, but the data did not reveal this due to the overall low frequency of short-tailed bat passes and insufficient sampling.

Short-tailed bats have been recorded crossing open grassland while commuting to foraging areas in Eglinton valley in Fiordland (O'Donnell et al., 1999). However, individual bats have been documented crossing between Pikiariki and Waipapa on only two occasions. In a recent home range analysis one transmitter carrying male was observed to travel from Pikiariki to Waipapa nightly to forage on the forest boundary (Toth et al., 2015a). Following this observation, DOC staff managed to capture and attach a transmitter to a single individual in Waipapa, near a patch of *Dactylanthus*. This bat was located at a communal roost in Pikiariki the following day (Tertia Thurley, Personal Communication). Guano from short-tailed bats roosting in Pikiariki still contained diphacinone residues in October 2013 (when there was bait in Waipapa but not in Pikiariki), indicating that bats must be moving back and forth between the two areas in sufficient numbers to make the residue concentration in the communal guano pile detectable (Dennis, 2015). To date, no solitary or communal roosts have been located inside the boundary of Waipapa. As both short-tailed bat individuals observed in Waipapa were also found at Pikiariki it seems unlikely that distinct populations are residing in each forest area.

While it can't be ruled out that bats may be using another area to cross the farmland, it is most likely the central gap in the short-tailed bat passes was a result of problems with sampling procedure. The monitored area was selected as it contains the farmland's most complete forest corridor between Pikiariki and Waipapa which bats may utilise. ABMs were left at each location for only 3 days, which increases the relative effects of factors such as weather on average passes. It is well known that other species of microbats are sensitive to temperature, going into episodes of torpor in cooler conditions, and over winter (Christie & Simpson, 2006; Czenze et al., 2017). Short-tailed bats are more likely to be active in warmer conditions with chances of them being active increasing with every 2°C raise of mean overnight temperature (Christie & Simpson, 2006). In addition, environmental conditions also have an effect on recording quality (Blumstein et al., 2011). Heavy rain and wind creates noise visible in the data output which decreases detection range masking passes which may still be there. The numbers of passes at all sites were highly variable between nights indicating a need for longer sampling periods to accurately model activity (Christie & Simpson, 2006). While these factors would also affect long-tailed bats, it may appear less obvious due to overall higher pass counts. Given the low overall number of short-tailed bat passes, a few consecutive days of poor conditions or simply low bat activity could result in an underestimation of average nightly passes, which would not be as obvious in the long-tailed bat data due to their higher overall frequency of passes. As this study utilised a subset of 33 ABMs systematically moved around the study area, there may be a perceived error between space and time. The apparent gap in short-tailed bat passes is from locations that were monitored on the same nights (shown by dark blue points in figure 2.4) which supports the idea that some external time factor may have been the cause.

This study used two different models of bat detector, a sacrifice made in order to increase area coverage and resolution. Variation in microphone sensitivity, software, and detection algorithms can affect data output even within the same model of detector (Adams et al., 2012), however the same set of detectors were used in each of the 10 areas. Not all individuals will be detected. Therefore, accurate analysis of detector arrays is difficult due to uncertainties in device sensitivity. This is however a downfall of most acoustic monitoring studies (Efford et al., 2009). Like most passive acoustic monitoring methods, this study was designed to produce only a measure of species presence or absence and provide an indication

of high use areas for more intensive research. The ABMs used are unlikely to produce false positive readings as they were manually identified. Highly ambiguous results were discarded, meaning nightly pass counts are more likely an underestimation than an overestimation.

Future Direction and Consequences:

It is impossible to identify individuals through echolocation detection making it difficult to confidently assign travel paths. This study has successfully determined the presence of both bat species on this farmland area and provided data on where they are mostly passing through. It has highlighted that more bats than expected may be using parts of Waipapa Ecological Area. The correlation between sites which recorded feeding buzzes and high activity areas suggest they may be used for feeding. This information can be explored further through radio tracking to determine whether the observed bat passes are the result of a few individuals spending a large amount of time foraging or flying around the area, or a larger number of individuals using the fragmented forest corridor primarily as a means of travel between the two large forests. A pilot study along these lines is described in chapter 3.

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3 Habitat Selection

Introduction

The analysis of habitat use and selection is vital for effective conservation and management practices (Sprague & Bateman, 2018), particularly as human activities can often result in clashes between conservation and land use interests (Tikkanen et al., 2018). Examples of this can be seen in small and large-scale infrastructure such as building houses, roads and windfarms, or conversion of native forest to farmland. Research on home range and habitat selection assumes that individuals act in a non-random manner (Mitchell & Powell, 2012) by choosing areas that may increase survival in terms of resource availability or absence of predators (Sprague & Bateman, 2018). In agricultural areas there are many conflicting factors which might affect habitat choice. Forest fragmentation is generally linked with higher insect diversity and abundance at fragment edges leading to an increase in abundance of insectivorous animals (Bereczki et al., 2015). This in turn attracts aerial and mammalian predators (Bereczki et al., 2015) causing use of open areas to incur a trade-off in food availability vs probability of predation. Fragmented forest corridors, however, may not always provide the protection that exposed areas lack. Kauffman et al. (2007) provided evidence of apex predators such as wolves utilising the high thoroughfare provided by habitat corridors, to create ambush points for prey (Kauffman et al., 2007).

Habitat loss and modification can restrict an individual's ability to access required resources, and limit ease of travel about the landscape (Santos et al., 2006). In species which evolved in continuous habitats, the understanding of altered behaviour in today's fragmented environments is fundamental to managing future survival and maintaining the integrity of remaining intact habitats (Delciellos et al., 2017). While some species are negatively impacted by habitat fragmentation resulting in a smaller habitable area (Hanski, 2015), many species of bat have been recorded using modified habitats as a means of transport to and from roost sites (Bernard & Fenton, 2003; Toth et al., 2015a). A large study on bat mobility by Bernard and Fenton (2003) was carried out in the naturally fragmented landscape of Central Amazonia, Brazil, which consists primarily of intact forests and fragments bordered by savannas. In their telemetry study of 23 individuals (from 8 different species) all were

observed crossing savannas. Distances in which these bats were in the open ranged from 500 m to 2.5 km. Similarly, in a home range study of New Zealand short-tailed bats, Toth et al. (2015a) observed one male commuting nightly over 2 km of open farmland between communal roosts and foraging territory.

Knowledge of habitat use is particularly important when a threatened species is dependent on specific conservation management (Rechetelo et al., 2016) as is the short-tailed bat in New Zealand. Populations of short-tailed bat rely on ongoing predator control (Pryde et al., 2005) through use of traps and vertebrate pesticides, including toxic baits laced with anticoagulant rodenticides such as pindone and diphacinone (O'Donnell et al., 2011). Past assessments of a similar programme in Eglinton Valley, Fiordland, New Zealand, revealed high survival rates with 99% of PIT-tagged individuals known to be alive one month post bait deployment, and 97% remained one month post toxin removal (O'Donnell et al., 2011). This pest control programme at Pureora spans the entirety of the communal roost areas and nearby intact continuous forest (in total > 1740 ha), but not however the adjacent farmland which includes forest fragments as well as open pasture.

In this study I investigate the habitat use and selection of the short-tailed bat over an area of farmland intersecting two main forest areas at Pureora Forest Park, New Zealand, through radio-tracking techniques. Pikiariki Ecological Area is home to a stable population of short-tailed bat, the only known location with an intact interaction between short-tailed bats and *Dactylanthus taylorii*, a threatened endemic flowering plant (Ecroyd, 1996). A mark-recapture project began in 2013 in order to monitor bat survival rates and population status. There are no up to date population counts, but the adult population was estimated to be approximately 800 adult bats using closed population mark-recapture techniques in November 2013 (Dennis, G., unpublished analysis). While there have been a number of previous studies on general short-tailed bat home range and habitat selection, both at Pureora Forest Park (Toth et al., 2015a) and other areas of New Zealand (Christie, 2006), this is the first study to my knowledge to focus specifically on the use of forest corridors and their surrounding exposed areas in New Zealand. While use of this farmland to travel between Pikiariki and the adjacent forest, Waipapa, by short-tailed bats has been inferred from previous acoustic monitoring (Chapter 2) and radio-telemetry methods it is currently unknown where exactly these bats are making regular commutes, how much time is spent in

fragmented areas, and the frequency in which individuals are resorting to using this periphery habitat. Here we target only individuals known to use this area (by selecting appropriate capture sites rather than utilising communal hotspots such as roosts) as the levels of deployed toxin for introduced pest control differs between Pikiariki and Waipapa as a result of the inferred usage by bats in the two areas. To reduce the levels of toxin exposure to short-tailed bats, all mammal-targeting bait is removed from Pikiariki by October when numbers of short-tailed bats begin to build in communal roosts. Bait remains in Waipapa however for the entire season as, despite there being evidence that bats that roost in Pikiariki were exposed to diphacinone deployed in Waipapa in 2013/14 (Dennis, 2015), there is a lack of knowledge about the number of individuals at risk.

Methods

Radio Telemetry:

Short-tailed bats were caught on a plot of private farmland between Waipapa and Pikiariki Ecological Area of Pureora Forest Park (Figure 2.3) from October 2017 to February 2018. Bats were caught using a combination of standing harp traps and mist nets at the locations of high activity inferred from acoustic monitoring (Chapter 2). Trap placements were intended to interrupt flight paths, and Audubon bird squeaker lures used, as suggested by the DOC Best Practice Manual of Conservation Techniques for Bats (Sedgeley et. al., 2012). Individuals caught in mist nets were removed as quickly as possible to minimise stress but those caught in harp traps could be left for up to 2 hours (Sedgeley et. al., 2012). Captured bats were assessed for suitability by considering pregnancy status, general body condition, and weight. It was ensured that the transmitter did not weigh more than 5% of the individuals' body weight (Brigham, 1988; (Sedgeley et. al., 2012). Blunt ended nail scissors were used to trim a patch of fur between the shoulder blades for radio transmitter attachment. Bats were fitted with Holohil BD-2 transmitters (Holohil Systems Ltd., Ontario, Canada) weighing 0.65 g with an aerial length of 160 mm using ADOS F2 contact glue (CRC Industries, New Zealand).

Radio tracking was carried out on the nights following transmitter attachment by 2-3 people using Sirtrack Ultra receivers each connected to a 3-Element Folding Yagi antenna (Sirtrack Limited, Hawkes Bay, New Zealand). On nights radio tracking was taking place, each person was stationed in a unique location in the study area from dusk waiting for a bat to pass. When a signal was picked up readings were initially taken as often as possible, and at

the same time by all observers who coordinated via handheld radios. GPS coordinates were noted and the bearing of the direction to the strongest signal taken using a handheld compass. Once it was determined that an individual was foraging rather than simply passing through the study area, the time between fixes was increased to a maximum of 15 minutes. On occasions when more than one bat was fitted with a transmitter at any one time (due to higher catch success on a particular night) the receivers were set to run on scan mode, changing channels every 10 seconds. Triangulation data were entered into LOAS Radio Telemetry Software 4.0 (Ecological Software Solutions LLC, USA). Estimated bat locations were mapped in QGIS 2.18 for visual screening. Each bat was tracked for a minimum of 4 nights, or until a signal had not been found (either in the study area or a known communal day roosts) for 5 days. In total 10 bats were tracked, with only 8 returning to the capture and study site for data to allow for data collection.

Data Screening and Error Calculations:

A total of 434 triangulations or biangulations (depending on signal strength and availability of all observers) were recorded for a sample of 8 out of the 10 bats tagged. Data were first screened for triangulations that did not intersect using LOAS Radio Telemetry Software 4.0. The remaining fixes were plotted onto an aerial map in QGIS to visually screen for points that exceeded realistic boundaries of the equipment. Fixes were removed if they were more than 300 m into the surrounding forest areas, or more than 2 km from any observer in the open farm landscape. These distances were deduced from observations of the equipment's capabilities throughout the study period. This removed 30.2% of the triangulation readings, resulting in 302 location fixes (table 3.1). The total number of fixes after screening for some bats was low due to their irregular use of the study area. It was not guaranteed that any individual would return on consecutive nights or stay within receiver range long enough to take numerous readings. This in addition to the short lifespan of a transmitter (approximately 2 weeks) and natural effects such as weather affected how many fixes could be obtained from each bat.

Fix location error was calculated by taking biangulations of transmitters at a fixed location in the study area. This allowed the calculation of point estimate error, and the

visualisation of the effects of distance on precision. 38 biangulations were taken for this location, which was unknown to those taking readings, and fixes were calculated using the same procedure as was with data collection. Location fixes were compared to the true transmitter location and the Location Error Method (LEM) was used to calculate distances between transmitter and location fix for each biangulation (Figure 3.1). LEM was used over other strategies such as the Error Polygon Method (EPM), which measures angle error, as it is a better indicator of point estimate rather than bearing precision (Zimmerman & Powell, 1995).

Table 3.1: Summary of the 10 bats caught during this study, detailing the channel number of the attached transmitter, sex (F = female, M = male), age (adult (A) or the current year's juvenile (J)). Also indicated is a female's determined breeding status showing nulliparous (NP) females who have never given birth who have hard to find nipples sometimes with tufts of fur on them ((Sedgeley et. al., 2012), date ranges in which a transmitter was scanned for, total number of triangulations taken, and the total number of usable fixes after data screening.

Bat (Chanel Number)	Sex	Age	Dates Tracked	Total Triangulations Recorded	Total Usable Fixes
08	F	A (NP)	17/10/2017 - 20/10/2017	90	75
10	F	A (NP)	31/10/2017 - 7/11/2017	8	8
12	F	A (NP)	21/11/2017 - 4/12/2017	26	21
16	M	A	4/12/2017 - 12/12/2017	55	26
18	F	A (NP)	16/12/2017 - 22/12/2017	6	6
72	F	A (P)	8/01/2018 - 16/01/2018	76	52
70	F	A (NP)	24/01/2018 - 2/02/2018	0	0
42	F	A (NP)	24/01/2018 - 2/02/2018	51	25
20	M	A	24/01/2018 - 2/02/2018	121	89
06	M	J	8/02/2018 - 16/02/2018	0	0
Total	7 F 3 M	9 A 1 J	17/10/2017 - 16/02/2018	434	302

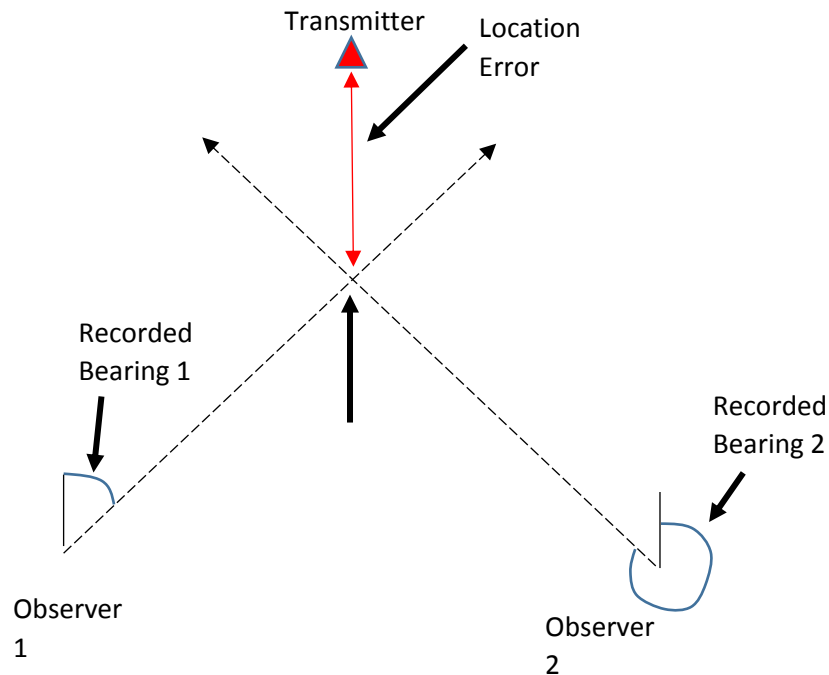


Figure 3.1: Illustration showing how to calculate location error from biangulations of transmitters at known locations, adapted from (Zimmerman & Powell, 1995). Red triangle shows the actual location of the transmitter, and dotted lines the direction of recorded bearings. Location error is depicted by the red line.

Error Analysis

Location error was calculated as the distance in meters between true and observed signal. Analysis of location error for the known transmitter location revealed moderate Western and North-Eastern directionality, particularly where location error is greater than 50 m (Figure 3.2). Individual bearings tended to be biased towards the left, suggesting this skew to be a result of inaccuracy in compass readings rather than poor telemetry methods. A moderate positive trend was observed when Location Error was plotted against signal distance (figure 3.3). To account for increased Location error with signal distance, Bontadina et. al. (2002) suggested assigning specific error values to distance range categories. Due to the speed in which the bats passed through the study area it was difficult to ensure observers were at similar distances from the transmitter, so the average location error was taken for all location fixes, coming to 55.7m. This probably overestimates error at short range but underestimates at large distances.

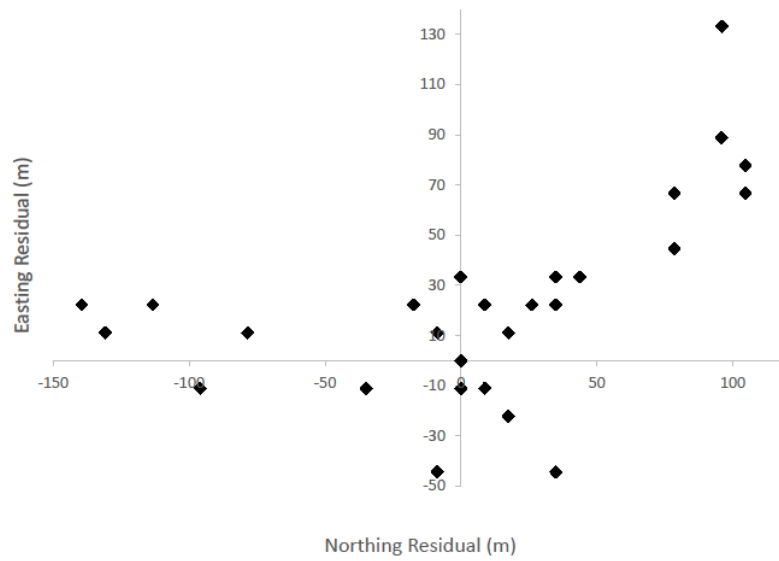


Figure 3.2: Location error of biangulation fixes in m, with 0,0 representing the known location of a fixed transmitter.

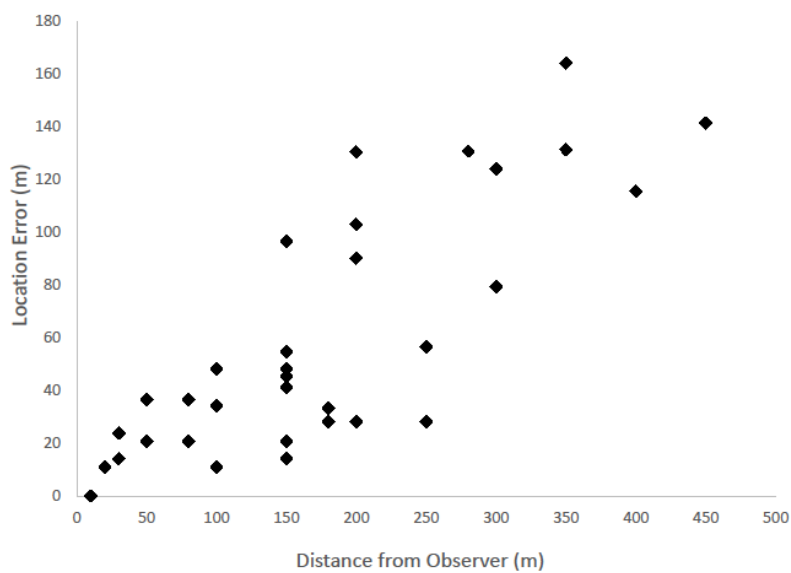


Figure 3.3: Relationship between location error (distance between true and estimated location of a transmitter) and the distance between observer and true transmitter location.

Habitat Selection Analysis

To determine the specific area collectively used by all 8 bats the 95% Minimum Convex Polygon (MCP) of all location fixes was calculated in R (package adehabitat) and an incremental plot produced in Ranges 9 (Anatrack Ltd, United Kingdom).

Habitat preference is said to exist if use is disproportionate to availability (Manly et al., 2007). Due to the small sample size ($n = 8$) the study area was divided into three broad habitat types (forest, stream gullies, and open farmland, figure 1 in Appendix I). Each location fix was buffered by the average location error radius and the total area of each habitat type which these points covered was calculated (figure 3.4). Habitat selection was assessed by comparing areas of habitat type used by location fixes for each bat to the total area of each habitat available. Habitat was considered to be available if it fell inside the 95% MCP. Due to the fragmentation of forest in the study area, individuals selecting this habitat type need to

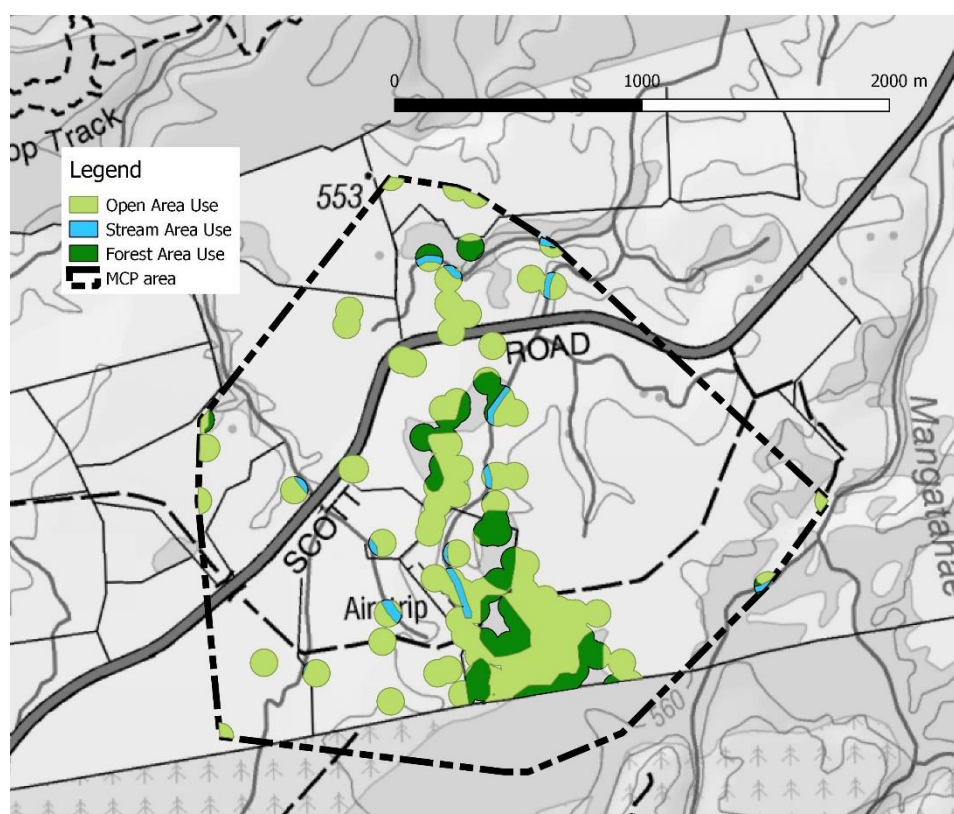


Figure 3.4: Areas used by eight short-tailed bats defined by triangulation location fixes buffered by a 55 m (average location error) radius, separated by habitat type (Forest, Stream valley, and Open areas). Grey areas represent landscape with no recorded location fixes, or forest which lies beyond the farm boundary. 95% minimum convex polygon of all location fixes is depicted by a dashed line. See figure 3, Appendix I for all location fixes.

travel through open areas to traverse the entire farm leading to an overestimation of open selection. To investigate this effect the study area was also divided into sections of hypothetical flight paths depicting areas that bats would use if they were traveling between forest fragments or aiming for stream gullies. The remaining areas were considered open (figure 2, Appendix I). All statistical analysis was performed on the log of the use ratios to remove the inherent bias produced by ratios. I added a constant of 0.5 ha to the raw data on numbers of ha of each habitat type used by each bat and numbers of ha available. This allowed the ratios of used: available habitat to be log transformed for analysis (Appendix III). I also tried adding a range of alternative constants (0.25 – 1 ha), and this confirmed that the choice of constant did not affect conclusions about whether there was significant habitat selection.

Table 3.2: Designated area use speed categories detailing speed range and assigned behaviour of short-tailed bats.

<i>Speed category (Km/h)</i>	<i>Area Use</i>	<i>Description</i>
<i>> 10</i>	Exclusively commuting	Bat is using the study area almost exclusively as a passage between Waipapa and Pikiariki Ecological Area
<i>1 – 10</i>	Both foraging and commuting	While primarily using the study area as a passage between Waipapa and Pikiariki Ecological Area, the bat may be foraging or resting along the way
<i>< 1</i>	Exclusively foraging	Bat is using the study area almost exclusively as a foraging territory

Trajectory Analysis of Area Usage

The trajectories of each bat for each night were plotted onto Aerial maps on QGIS (Appendix II) to assess the directions of travel and infer reasons of habitat use. In previous radiotracking studies, short-tailed bats have been seen to fly up to 60 km/h while commuting (O'Donnell, 2001). However, the fastest speed recorded by us was 28 km/h in which Bat 1 travelled from

communal roost 6 (CR6) to the study area (approximately 4.2 km) in 9 minutes. An individual bat's speed per night was calculated by comparing distance travelled with time within receiver range, and three broad speed categories were identified to act as a measure of general area use (Table 3.2). These three speed categories were selected to encompass all possible actions. If the study area was part of an individual's foraging range it could spend all night within receiver signal resulting in net speeds close to zero km/h, which could not be matched by any individual with shorter lengths of time within receiver range. The lower limit of 10 km/h for bats using the area almost exclusively for travelling was selected to account for variation in individual flight speeds, and any changes in activity due to being in a fragmented landscape. Throughout the study period no speed calculated from triangulations matched the maximum recorded speed of 28km/h which may suggest altered behaviour in open or fragmented areas. The middle speed category accounts for the remaining observations.

Results

Home Range

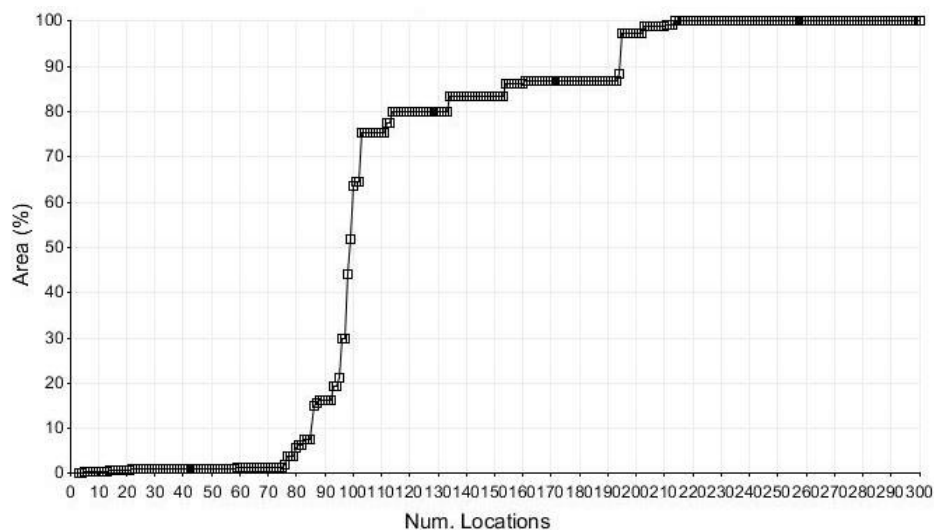


Figure 3.5: Cumulative minimum convex polygon area over 303 total fixes showing the change in area with each additional data fix.

The 95% minimum convex polygon of all location fixes for the eight bats was calculated to be 413 ha, and covered a large proportion of the surveyed area (Figure 3.4). The cumulative MCP area was analysed via an incremental plot revealing a plateau (Figure 3.5).

Habitat composition

Within the 95% MCP, 44 ha (11%), 21 ha (5%), and 320 ha (78%) were assigned to Forest, Stream Valley, and Open habitats respectively. The remaining 6% fell into forest edge habitat of Pikiariki (Appendix I).

Habitat Selection

Forest areas were positively selected for by all individuals with a mean use ratio of 2.22:1, meaning on average bats used forest habitats 2.22 times more than availability (Univariate t test, $p < 0.001$). Farmland use was disproportionately low with a use ratio of 0.851 (Univariate t test, $p = 0.006$). Stream Valley habitat usage ratios did not significantly differ from 1 (univariate t test, $p = 0.607$) meaning there is no evidence that usage was either selected for or against (Table 3.3).

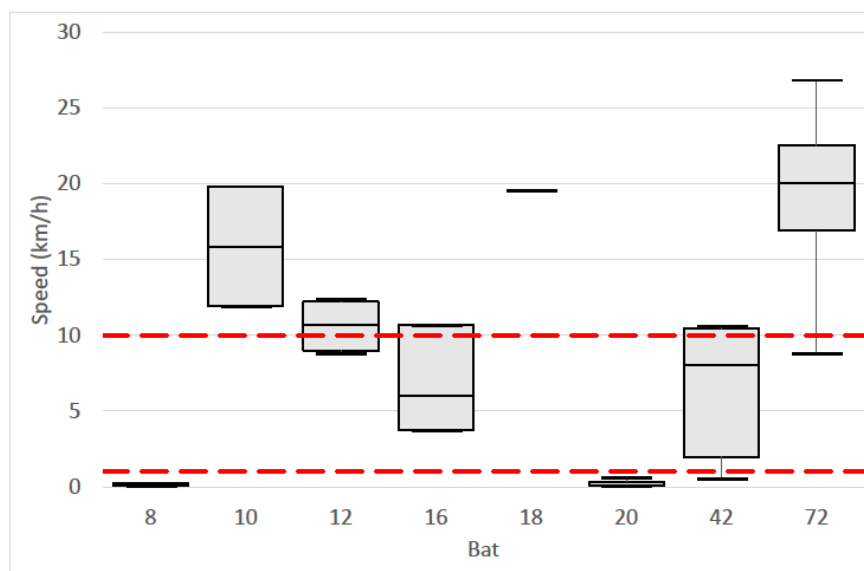


Figure 3.6: Box and whisker plots of flight speeds for all eight tracked individuals. Red dotted lines indicate boundaries of assigned behaviours (where $x < 1$ km/h shows foraging, $x > 10$ km/h suggests travelling, and $1 < x < 10$ km/h represents a combination of both activities).

Hypothetical paths of habitat type were assigned to the area to account for fixes taken in open areas that were actually snapshots of an individual (who would usually avoid open areas) that was travelling between fragments. Bats travelled through areas assigned to “forest flight path” almost three times more than was proportionately available (univariate t test, $p < 0.001$). The logged use ratios of “stream valley flight path” was not significantly different to 0 (univariate t test, $p = 0.161$) and negative selection was indicated for the remaining open farmland areas (univariate t tests, $p < 0.001$) (Table 3.4).

Table 3.3: Mean habitat use ratios, and logged use ratios with associated p-values and t-statistic for each habitat type in area use analysis of short-tailed bats. Univariate t-tests tested if mean logged ratios differed from 0 (where >0 is overproportionate use). Mean habitat use ratio is calculated from all 8 bats

<i>Habitat Type</i>	<i>Mean Ratio</i>	<i>Mean Log Ratio</i>	<i>t</i>	<i>p</i>
<i>Forest</i>	2.22	0.359	8.07	< 0.001
<i>Stream Valley</i>	0.697	-0.124	-0.54	0.607
<i>Open Farmland</i>	0.851	-0.116	-3.86	0.006

Table 3.4: Mean path type use ratios, and mean logged path use ratios with associated p-values and t-statistic for each path type in area use analysis of short-tailed bats. Univariate t-tests tested if mean ratios differed from 0.

<i>Path Type</i>	<i>Mean Ratio</i>	<i>Mean log ratio</i>	<i>t</i>	<i>p</i>
<i>Forest</i>	2.95	0.421	11.55	< 0.001
<i>Stream Valley</i>	0.559	-0.410	-1.57	0.161
<i>Remaining Farmland</i>	0.274	-0.553	-6.09	<0.001

Levels of habitat preference did vary between bats. However, forest was consistently selected for, and open areas selected against (Figure 3.7). The same result can be seen for selection of paths of habitat type, but with more exaggerated selection for forest path and against open areas (Figure 3.8).

Trajectory and Area Use

Visual analysis of flight paths plotted in QGIS (Appendix II) predominantly reveal paths that cross from Waipapa to Pikiariki and vice versa. There was a large variation in the average speed of each individual over each of the nights they were tracked (ANOVA, $F = 18.3$, $p < 0.01$, see table 3.5, Figure 3.6) Of the eight bats that returned to the study area, four were using the farmland almost exclusively to travel between the two large forest blocks, two were using it to cross but taking time to forage or rest, and the remaining two used the farmland as an extension of their foraging range (table 3.5).

Table 3.5: Assigned behaviour of each individual short-tailed bat as defined by average flight speed. Table shows the total number of times each bat was recorded on the farmland area (count) as well as variance in speed among the crossings for that bat.

Bat	Count (replications)	Average Speed (km/h)	Variance	Assigned behaviour
8	4	0.115	0.001	Foraging
10	2	15.9	31.4	Travelling
12	4	10.6	2.94	Travelling
16	3	6.80	12.4	Opportunistic
18	1	19.6	-	Travelling
20	5	0.179	0.057	Foraging
42	4	6.81	21.1	Opportunistic
72	8	19.5	28.4	Travelling

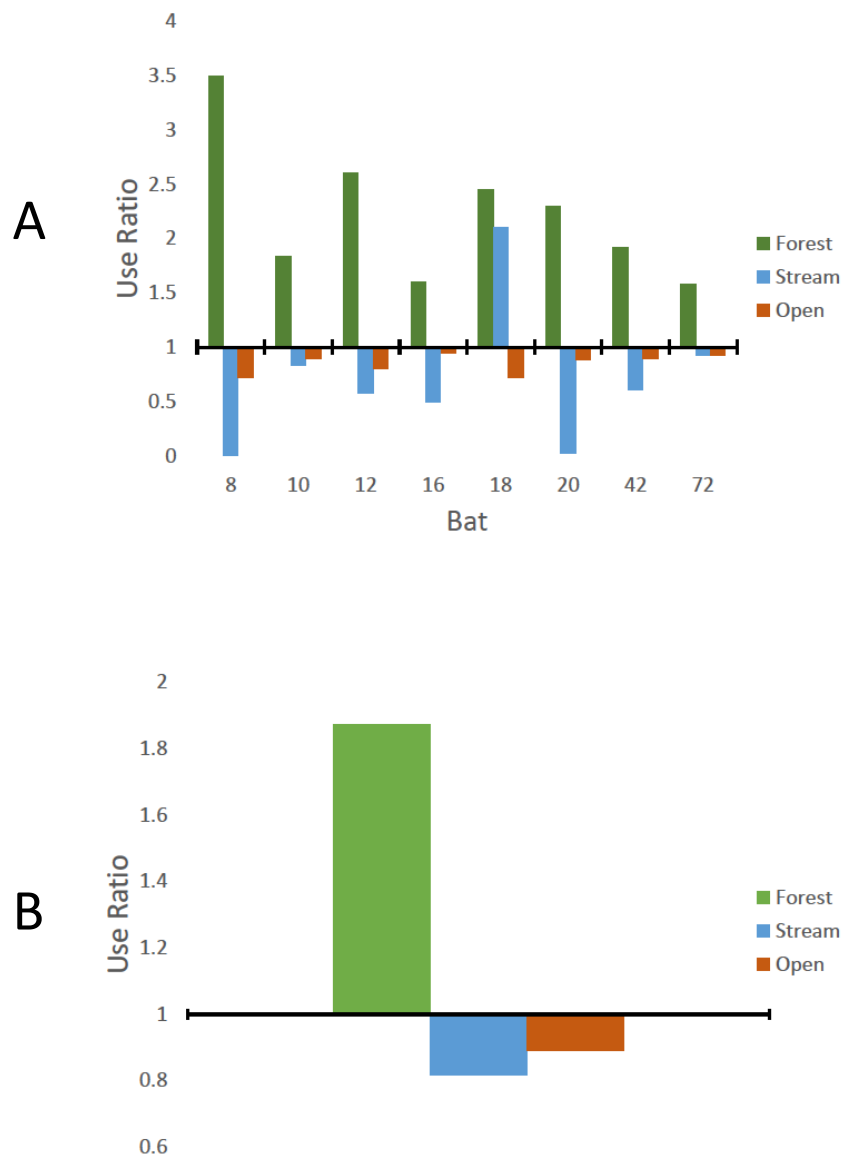


Figure 3.7: Area use ratios in short-tailed bats (A) per bat and (B) using combined data. Bars above the horizontal line represent selection for the habitat type. Bars below the horizontal line represent selection against the habitat type.

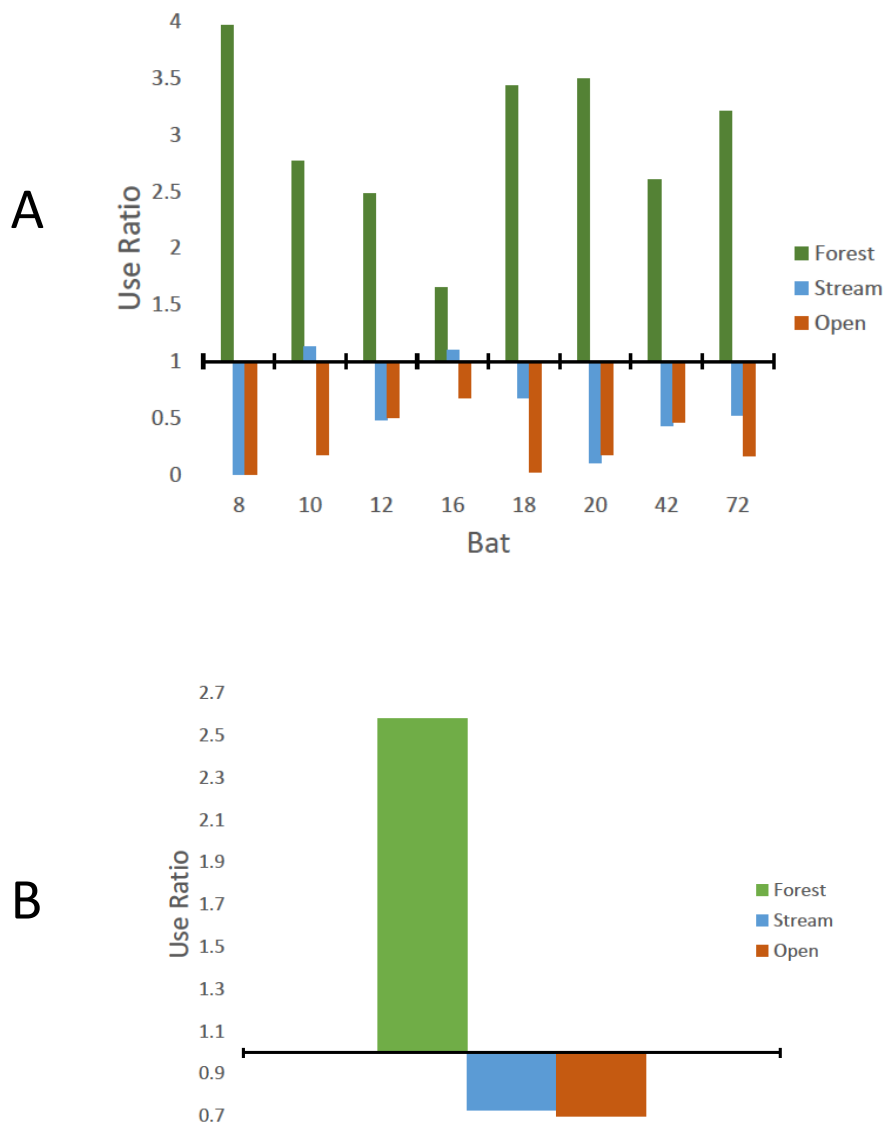


Figure 3.8: Area use ratios for assigned path types in short-tailed bats (A) per bat and (B) using combined data. Bars above the horizontal line represent selection for the habitat path type. Bars below the horizontal line represent selection against the habitat path type.

Discussion

Modern day rural environments are dominated by open areas and pasture for agriculture, leaving only a mosaic of natural (usually regenerated) forest and areas of vegetation that may force forest dwelling species such as the short-tailed bat to inhabit unfavourable environments. As a result, the conservation of such species relies on their ability to adapt and make use of modified landscapes (Lumsden & Bennett, 2005) and our knowledge of what areas they are using. The short-tailed bat has a wing morphology comparable to other species of microbat, but due to its large range of foraging methods it is not specialised for a particular flight strategy (Lloyd, 2001). While they usually travel in the relatively obstacle-free layer of airspace between the understory and main canopy, they are also able to travel quickly with high manoeuvrability through cluttered environments (Lloyd, 2001). As well as aerial insectivory it is thought that short-tailed bats spend up to 30% of their foraging time crawling and burrowing in search of arthropods or pollen (Riskin et al., 2006) making old-growth forests the ideal habitat type for the species due to the prominence of large trees for communal roosting, and abundance of prey in deep leaf litter (Lloyd, 2005).

Habitat selection and area composition

The short-tailed bats used in this study were seen to be highly selective in their habitat use of the fragmented landscape at Pureora Forest Park. All individuals selected for forest habitat and against open and stream valley areas (excluding one individual who also selected for stream valley areas). In total, short-tailed bats were located within forest habitat 1.9 times more than proportionate availability, but there was considerable variation between individuals (use ratios ranged from 1.6 to 3.5). This information complements conclusions made by Toth et al. (2015a) and Cummings (2013) who stated that short-tailed bats show behavioural plasticity in fragmented environments to exploit alternative habits despite being known as an obligatory forest dwelling species. They also found habitat composition of home ranges to be non-random, with native forest and exotic plantations being selected for, and open areas selected against. A similar pattern was observed in 10 species of insectivorous bats in Australia (Lumsden & Bennett, 2005) where bat abundance and vegetation density were positively correlated. All species were recorded in open areas, but in significantly lower numbers than surrounding forests or fragments. The Little Yellow-shouldered Bat (*Sturnira*

lilium) moves freely between forest and savannah mosaics in South America, supporting the idea that bats can and will move between forests and their surrounding fragments and back in a single night (Loayza & Loiselle, 2008).

With the assumption that short-tailed bats are primarily using the study area to cross between Pikiariki and Waipapa, a bat must traverse open areas to travel between forest fragments. Each location fix is purely a snapshot of an individual's location at a particular time, meaning fixes in open areas are inevitable even if the areas are usually avoided. Assigning hypothetical forest and stream valley flight paths accounted for open area use between forest fragments, further increasing selection for this habitat compared to the other two area types. While available habitat consisted of only 11% forest cover, the area which short-tailed bats are selecting to use the farmland is that which contains the shortest distances of open space between adjacent patches of vegetation, as seen on aerial photographs. This suggests an overall tendency to avoid large open areas if a covered alternative is available, an observation which to my knowledge has not been previously reported in short-tailed bats. This could be a result of predator avoidance, or using treelines as acoustic landmarks for orientation (Verboom & Spoelstra, 1999). Predation is a strong selective force encouraging bats to forage and commute in areas where they are more likely to avoid attack. This reason was suggested to be unlikely by O'Donnell et al. (2006) as the short-tailed bats' primary predators, the morepork (*Ninox novaeseelandiae*) and now extinct laughing owl (*Scelogalax albifacies*), both hunt(ed) within forest interiors. Microchiroptera are also known to use echolocation around solid objects for orientation (Barchi et al., 2013) which are less abundant in open areas. This does not seem to be a constraint, however, as many other bat species are also seen to use open areas in low numbers (Lumsden & Bennett, 2005; Loayza & Loiselle, 2008). It is also possible, for individuals that were foraging, that habitat selection was governed by insect distribution which is strongly affected by wind strength (Verboom & Spoelstra, 1999). Open farmland areas of the study site are much more exposed and prone to strong winds than the sheltered interiors of forest fragments. Like many endemic species short-tailed bats have a long evolutionary history living in old-growth continuous forests (Lloyd, 2005) meaning they may simply be uncomfortable out in the open.

Trajectory and Area Usage Analysis

How a habitat is used by bats depends on environmental conditions, availability of prey and vegetation density (Luszcz & Barclay, 2016). In this study, the 95% MCP was used to define the area available to all eight bats rather than determining individual home ranges. While my methods don't allow us to directly observe exactly how short-tailed bats spend their time in this fragmented landscape, inferences were made through visual trajectory analysis and the time spent within receiver range. Of the 8 individuals who returned to the study area, only two were deemed to be actively using it as foraging territory (individuals 8 and 20). Flight trajectories showed that bat 8 was primarily foraging at the Pikiariki farmland border around a solitary day roost, occasionally venturing into nearby forest fragments and back to communal roosts every few nights. This is not an uncommon behaviour for short-tailed bats, which regularly switch between solitary and communal day roosts (Carter & Riskin, 2006; Sedgeley, 2006) and their foraging territories. Bat 20, however, was spending entire nights moving between forest fragments and open areas. This was also the only individual throughout the entire sampling period that was captured more than once, possibly reflecting the lengths of time spent in the area and the presence of spatial memory of specific flight paths seen in other bat species (Barchi et al., 2013).

The remaining 6 individuals were determined to be using the area primarily to travel between Pikiariki Ecological Area and Waipapa Forest, a 5 km minimum commute. As it was beyond the scope of this study to investigate bat activity in Waipapa itself, total trip distances could not be determined further. It is common for bat species to travel large distances between roosts and foraging grounds. The greater noctule bat (*Nyctalus lasiopterus*) has been observed to travel up to 130 km in order to meet both roosting and foraging requirements, and has communal roosts used by the same population up to 90 km apart (Popa-Lisseanu et al., 2009). Populations of short-tailed bat at Rangataua (Ohakune, New Zealand) and the Eglinton Valley (Fiordland National Park, New Zealand) have been seen to frequently commute over 10 km from day roosts (Lloyd, 2001) which is not dissimilar to observations made in this study. To date there are no confirmed roosts in Waipapa forest but due to the directions of travel in the early evening seen in this study it can be assumed that some individuals at least have solitary day roosts in the area. Waipapa is a well-established podocarp forest with patches of *D. taylorii* (Cummings, 2013) with similar vegetation

composition to the nearby Pikiariki Ecological Area, so there is no apparent reason bats would avoid roosting or foraging there.

Area Utilisation Demographics

The home-range constraints of an individual vary by their energetic and metabolic requirements, which change with age, sex, and reproduction status (Christie & O'Donnell, 2014) as well as resource availability and population size (Borkin & Parsons, 2011). It is therefore important to understand the energy needs of short-tailed bats at the time of the study, which spanned a period including mating, birth, lactation and fledging young. There are many different mating strategies among bat species, such as where a few males protect multiple females (Storz et al., 2000) or swarming, where many individuals simultaneously congregate at a particular area for mass breeding (Rivers et al., 2006). The short-tailed bat is one of only two bat species known to show lek breeding behaviour (Toth, 2016). Males take turns defending areas that provide no resources, and perform sexual calls and displays for females who will select a male based on display characteristics (Toth, 2016). Short-tailed bats mate in the summer and autumn, with implantation or development paused throughout winter while bats are in torpor (Carter & Riskin, 2006). Gestation continues from spring, until a pup is born in summer. Males begin singing from September in preparation for mating again in summer (Carter & Riskin, 2006). This means that during our study period (October to March) both reproductive females and singing males would have had high metabolic costs. Of our sample of 10 individuals caught in forest fragments most (7) were adult females. Of the remaining three males, one (bat 6) was the only bat out of the 10 that was thought to be juvenile. This is a result that parallels research by Rocha et al. (2017) in which female frugivorous bats (*Carollia perspicillata* and *Rhinophylla pumilio*) were more abundant on forest edges than males, but sex ratios were even in forest interiors. This pattern was most prominent in the breeding season, the time of year when this study was carried out. Sex distributions were the opposite, however, in long-tailed bats where males in plantation forest more often selected edges and open unplanted areas to be part of their home range than females (Borkin & Parsons, 2011).

While a sample of 10 individuals is unlikely to accurately represent the true sex ratio of bats using the area it may still be indicative of the types of individuals travelling to Waipapa. No captured females were thought to be pregnant, with visible nipples found on only one (with no signs of milk production). This is consistent with the idea that reproductive females, having higher energy requirements, will forage closer to communal roosts and/or dependent offspring (Christie & O'Donnell, 2014). This could suggest that young, non-breeding individuals are most likely to travel long distances to surrounding forests. The individuals caught for this study indicated that these individuals travel with destination in mind, heading to the farmland area immediately after emergence with travel times ranging from 9 to 30 minutes. These bats were flying directly to their Waipapa destination, consistent with the idea that short-tailed bats have specific foraging areas that they return to often (Cummings, 2013).

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4 General Discussion

Pureora Forest park is an ecologically unique area dominated by indigenous podocarp forest (Husheer, 2007), and one of the few known remaining forests to support both the short-tailed bat and the ground flowering plant *Dactylanthus taylorii*, maintaining their unique pollination relationship. It is surrounded and intersected by agricultural farmland and exotic pine plantations, resulting in a highly fragmented environment. Investigating how a species such as the short-tailed bat interacts with such an environment becomes interesting when it is historically defined as exclusively forest dwelling (Toth et al., 2015a). This knowledge becomes even more important when a species is threatened, or dependent on specific management plans for conservation (Rechetelo et al., 2016). The population of short-tailed bats at Pureora Forest Park has in the past fallen victim to accidental poisoning as a consequence of mammalian predator pest control. The research presented in this thesis provided information on how short-tailed bats navigate a fragmented landscape and utilise the nearby Waipapa Ecological Area, and that this habitat is also used as a foraging ground. This information can assist in development of management plans aiming to minimise bat exposure to toxins both in main forest areas and surrounding fragments.

Pureora Pest Control – A Short History

The consequences of secondary poisoning of short-tailed bats was first revealed when 115 bats were found dead or dying between 9 January and 6 February 2009 (Dennis & Gartrell, 2015). During this baiting season, the first-generation anticoagulant diphacinone was formulated into a paste that was held in biodegradable plastic bags and stapled to trees (Dennis & Gartrell, 2015). Upon post mortem, diphacinone was identified in 10 out of 12 livers tested, and in two samples of milk extracted from the stomachs of dead pups (Dennis & Gartrell, 2015). It is likely that toxicity occurred through secondary poisoning (Dennis, unpublished data). Previous bait acceptance trials in captive short-tailed bats revealed they are unlikely to consume bait in the form of pellets (Lloyd, 1994) but do not necessarily avoid pastes as was used during this time (Beath et al., 2004). Short-tailed bats may have received secondary poisoning through eating invertebrates such as weta, which may have also had

greater exposure to diphacinone when distributed in such a way. Subsequent pest control has used 1080 cereal baits dropped from the air and pellet baits (diphacinone and pindone) distributed in bait stations. The timings of bait placement have been altered to avoid periods of high bat activity in an attempt to reduce exposure (Thurley, 2017). At the time of this study pellets containing the anticoagulant pindone placed in bait stations were being used to control rat populations in Pikiariki and Waipapa. Bait was removed from Pikiariki, the location of communal roosts, in October but was left in Waipapa throughout the entire baiting season (August – March). This new regime has been used since 2015. Changing bait presentation and delivery methods (from paste baits in biodegradable bags to hard pellets in bait stations) dramatically reduced the risk of mortality of bats from toxins. However, dead bats and guano still contained residues, although no dead bats containing residues did not display signs of anticoagulant poisoning (Dennis, 2015). Changing pest control timings in Pikiariki from 8 months to 2 months has further reduced the risk of exposure of bats to anticoagulant toxins (Thurley, 2016).

Monitoring of bats in 2013 after an operation using Diphacinone pellets held in bait stations revealed this distribution method to have little or no effect on bat survival. However traces of toxin in bat guano revealed they were still in some way exposed to the bait (Dennis, 2015). Residues in guano and bat tissue detected when baits were not present in Pikiariki must have been encountered when pest control operations were taking place in Waipapa (Dennis, 2015; Thurley, 2017). While this population of short-tailed bats is being exposed to low levels of toxin which has no clear correlation to survival, the consequences of prolonged exposure to anticoagulant is still unknown. It may be only a small portion of the population travelling to Waipapa, yet they manage to accumulate enough toxin for it to be detectable in regularly collected guano samples (Dennis, 2015; Thurley, 2016). While there is no evidence of detrimental effects of low-level toxin exposure it is still unknown how long-term toxic accumulation affects an individual. A mark-recapture project to assess survival rates of short-tailed bats began in 2013 in which Passive Integrated Transponder (PIT) tags were used to mark individuals, and Radio Frequency Identification (RFID) loggers situated at communal roosts recorded “recaptures” (Thurley, 2017). Monitoring thus far has suggested at lower survival rates from February to April (Thurley, 2017), with all 14 (as of 26/03/2016) dead bats sent to post mortem testing positive for Diphacinone or Pindone in liver samples (depending

on which toxin was used in that season), though none showed typical signs of anticoagulant poisoning such as internal bleeding (Thurley, Personal Communication), however, without pest control bat numbers are likely to decline (O'Donnell et al., 2018).

In 2013/2014 traces of diphacinone appeared in guano and tissue samples of dead bats in Pikiariki in October and April, while baits were present in Waipapa (Aug-Apr) but not in Pikiariki (Nov-Mar). Since 2015 all baits have been removed from Pikiariki in October each year, prior to the peak breeding season. However traces of pindone or diphacinone continue to be detected in guano and liver samples after this time indicating exposure of bats to toxin in Waipapa also occurs during this period (Thurley, 2017). Little is known about short-tailed bat activity in Waipapa nor the pathway with which accidental toxicity has occurred. The research presented here confirms that some individuals utilise Waipapa and surrounding farmland areas, highlighting the importance of studying movements and habitat use to inform conservation management.

Bat presence in farmland area

Acoustic monitoring is a method of presence or absence detection commonly used to determine activity levels or abundance (Efford et al., 2009), and provides an unobtrusive detection method for rare or cryptic (nocturnal or shy) species such as both the short-tailed and long-tailed bat. These two microbat species make vocalisations audible to humans (Toth et al., 2015b) as well as high-frequency ultrasonic echolocation clicks used for prey detection and orientation (Verboom & Spoelstra, 1999). It is these echolocation clicks that become the most important vocalisation for the automatic bat monitors (ABMs) developed by the New Zealand Department of Conservation. These ABMs are set to turn on only when noise within this frequency range is detected. While some rodents, insects, and rustling sound, or bad weather may also trigger detection, the limited frequency range excludes most other night-time noise, making it easier to sort through recordings.

To determine the activity levels of bats over the farmland area between Pikiariki and Waipapa 33 ABMs were set out systematically in 10 defined sub areas from 19 September to 19 October 2017 and set to activate nightly between 19:00 and 06:00. Each ABM remained in the same location for a minimum of 3 nights, resulting in a total of 225 unique monitoring

locations and 7425 h of recorded activity. The data obtained were transformed into heatmaps showing bat activity defined by the average number of bat passes detected each night at each location, revealing that both bat species have a higher number of passes near forest fragments that intersect the farmland than open space. This pattern is seen in many bat species that prefer edge habitats to open space (O'Donnell et al., 2006; Wolcott & Vulinec, 2012) and may reflect prey abundance (Verboom & Spoelstra, 1999), predator protection (Wolcott & Vulinec, 2012), or efficiency of orientation (Barchi et al., 2013). Open areas do not appear to be a constraint for bats as both New Zealand bat species (and many others worldwide) are still seen to fly through open spaces even though they do so infrequently (Lumsden & Bennett, 2005; Loayza & Loiselle, 2008).

My research confirmed short-tailed bat presence on the area of farmland that divides Pikiariki Ecological Area and Waipapa, with most monitors near forest fragments detecting between 5 and 25 passes per night, making them vulnerable to toxins that have been distributed both in Waipapa and on private farmland. Detectors were not placed inside Waipapa to assess bat presence there. However, bats could still suffer from secondary toxicity by ingesting poisoned arthropods that have moved to the edges of Waipapa, and foraging buzzes revealed both New Zealand bat species spend at least some of their time foraging in fragments and on the Waipapa boundary. The information obtained from ABM data has limitations, such as being unable to distinguish between individuals. Radio tracking was used to further investigate habitat use and selection.

Habitat Selection and Area Use

By catching short-tailed bats at hotspots revealed through acoustic monitoring and attaching transmitters it was revealed that bats are routinely crossing between Pikiariki and Waipapa, and actively avoiding large areas of open space. The section of farmland through which these individuals were crossing was that with the most complete forest corridor and therefore the smallest amount of open space. All studied individuals selected for forested areas over the other two habitat types, overall being recorded in forest 1.9 times more than they should be if all habitat types were selected for equally. This has been observed in short-tailed bats by Toth et al. (2015a) and Cummings (2013), and in other species in Australia and South America (Lumsden & Bennett, 2005; Loayza & Loiselle, 2008). In all of these cases, bat habitat preference was associated with vegetation density, with evidence of individuals moving

between forest fragments. This inevitably results in time spent in open areas even while selecting for forest fragments. To account for this, I assigned hypothetical flight paths to the area so that open space between forest fragments or stream valleys were considered forest or stream habitat for the purposes of analysis. This further confirmed selection for forest habitat, and a tendency to minimise time spent in open areas by finding the path with shortest open exposure time. This is the first study to my knowledge which has demonstrated this behaviour in short-tailed bats and highlights the importance of forest corridors through agricultural areas.

There are many suggested hypotheses as to why animals such as the short-tailed bat may avoid exposed areas. These hypotheses include predator avoidance, food availability (Verboom & Spoelstra, 1999), and the need for acoustic landmarks for echolocation and orientation (Barchi et al., 2013). The predator-avoidance hypothesis was thought to be unlikely by O'Donnell et al. (2006), as the bats' primary predators (historically the now extinct laughing owl *Scelogalax albifacies*, currently the morepork *Ninox novaeseelandiae*) hunt within the forest interior. For foraging individuals, forest selection could have been influenced by insect distribution which is strongly affected by wind strength (Verboom & Spoelstra, 1999). The open farmland areas of the study site were significantly more exposed and prone to high winds than the sheltered forest fragment interiors. Short-tailed bats are thought to spend up to 30% of their foraging time on the forest floor, crawling even burrowing through leaf litter in search of food (Riskin et al., 2006). In this sense, forest interiors also provide better habitat for ground-dwelling insects that bats can prey on. All species of microchiroptera interpret echolocation clicks bouncing off solid surfaces for orientation (Barchi et al., 2013). Such solid surfaces are much less abundant in open areas. While this may be a deterrent, it does not seem to be a constraint on travel as many other bat species are also seen to use open areas in low numbers (Lumsden & Bennett, 2005; Loayza & Loiselle, 2008).

It was also confirmed in this study that some individuals were travelling to Waipapa and back in a single night. While the methods used in this study did not allow direct observations of exactly how short-tailed bats spend their time in the fragmented landscape, inferences could be made through visual flight-path analysis and the lengths of time spent within receiver range. Two of the eight returning individuals (08 and 20) were routinely within

receiver range for long enough to be actively foraging in the area. Individual 08 was found to have a solitary roost on the farmland border of Pikiariki, venturing into forest fragments and back to communal roosts throughout the night. This behaviour is seen commonly in short-tailed bats which regularly travel between solitary and communal day roosts (Carter & Riskin, 2006; Sedgeley, 2006) and their foraging territory. Bat 20 spent whole nights foraging in and around forest fragments, and days roosting either in Pikiariki communal roosts or solitary roosts (assumed to be in Waipapa due to the direction of flight upon entry into receiver range). The remaining 6 individuals spent significantly less time within receiver range, so were probably crossing directly between Pikiariki and Waipapa, perhaps resting or feeding opportunistically along the way. On almost all occasions, however, bats arriving from the direction of Pikiariki would disappear into Waipapa for the remainder of the night and vice versa, a total trip of over 5 km from known communal roosts in Pikiariki. Many bat species commonly travel large distances between roosts and foraging areas; one of the largest distances is seen in the Greater Noctule Bat (*Nyctalus lasiopterus*) which has been observed travelling up to 130 km to fulfil roosting and foraging requirements (Popa-Lisseanu et al., 2009).

The home-range constraints of an individual are defined by its energy requirements, which depend on its age, sex, and reproductive status, and also by resource availability and population density (O'Donnell, 2001; Borkin & Parsons, 2011; Christie & O'Donnell, 2014). It is therefore possible that the sex and age of bats using the area might change throughout the year. This study covered a period that included mating, birth, lactation and fledging young, meaning metabolic costs would have been high for all reproductive adults. The short-tailed bat is one of two bat species that performs lek breeding behaviour in which males take turns defending resource-poor areas and perform sexual calls and displays. Females will select a male based on the characteristics of his display (Toth, 2016). Of our sample of 10 individuals caught in forest fragments most were adult females ($n = 7$). Of the remaining three males, one (bat 6) was the only bat thought to be juvenile captured throughout the study period. A similar pattern was seen by Rocha et al. (2017) where female frugivorous bats (*Carollia perspicillata* and *Rhinophylla pumilio*) were more abundant than males on forest edges. However, sex ratios were even in forest interiors. This pattern was also most prominent in the breeding season. This pattern was reversed, however, in long-tailed bats in plantation

forest where males more often selected edges and open unplanted areas to be part of their home range than females (Borkin & Parsons, 2011). While this small sample size ($n = 10$) gives imprecise information about the true sex ratios of bats using the area it can still be used as an indicator of what individuals are travelling to Waipapa. No captured females were thought to be pregnant or showed signs of milk production. Visible nipples were found on only one which is consistent with the idea that reproductive females, having higher energy requirements, will stay closer to communal roosts and/or dependent offspring (Christie & O'Donnell, 2014). This could suggest that young, non-breeding individuals are most likely to travel long distances to surrounding forests. Bats were flying directly to their Waipapa destination after emergence from communal roosts, consistent with the idea that short-tailed bats have specific foraging areas which they return to often (Cummings, 2013), in this case in or around Waipapa.

Recommendations

The results from this study reveal that a large number of the short-tailed bat population at Pikiariki Ecological Area in Pureora Forest Park are travelling distances of over 5 km nightly to nearby Waipapa Forest (and often back again), where pest-control toxin is deployed for the entire season. The information provided through radio tracking complemented that obtained through acoustic monitoring in Chapter 2 and confirmed that short-tailed bats were primarily using this farmland as a flyway between Pikiariki Ecological Area and Waipapa. Catching and tracking individual bats allows us to examine the demographic of bats using the area, and therefore make predictions about bat activity in Waipapa. While it was beyond the scope of this project to monitor activity or search for roosts in Waipapa, it did confirm that some non-breeding individuals were using the area as a foraging ground, and possible day roosts. Previous video footage had seen short-tailed bats also feeding on *Dactylanthus taylorii* on the edge of Waipapa (Cummings et al., 2014). It would therefore be beneficial for future management plans to further investigate the possibility of roost sites in the area. It is also still unknown whether an independent colony resides in Waipapa, with its own communal roosts, which interacts with the Pikiariki population, or if there is only the one currently known colony. While the idea of two populations seems unlikely (as all tagged individuals returned more often than not to communal day roosts in Pikiariki) confirming this through a larger

sampling effort and analysis of activity within Waipapa would allow DOC to develop an efficient species management plan in regard to control of introduced mammalian predators.

Toxin could also be ingested by short-tailed bats through insects (such as weta or mosquito) which have come into contact with poison. This could result in high levels of toxin ingestion, as four insect orders (Coleoptera, Lepidoptera, Diptera and Orthoptera) are thought to make up at least 50% of their diet (Arkins et al., 1999). It would be useful to study the diets of short-tailed bats in this area to determine if this is a likely route of exposure. I have revealed that some bats forage in marginal habitats on private land, suggesting a need for implementation of safe pest control at these sites. Stronger toxins are often used on private land so the risks to short-tailed bats could be higher. As I have confirmed that a number of individuals actively travel to Waipapa, I recommend that more research be carried out on bat activity levels within Waipapa forest itself, beginning with a comprehensive acoustic monitoring study using the pre-existing 100 m x 100 m bait station grid in the area. Initially, broad surveys could be carried out by deploying acoustic monitors every five stations, on every fifth line. Areas of high activity (more than 5-10 passes per night) can be more intensively surveyed by decreasing distances between monitors to 100 m or less. My study focused on only a small area. It is likely that bats are also travelling to Waipapa from other areas of Pureora Forest Park, meaning forest use might be higher than currently thought. If high activity is found in future study, pest control operations in the area need to be modified with bat activity in mind. If the primary method of toxin ingestion is deemed to be secondary, via insects and other arthropods, I recommend investing in research into development of insect-detering bait to reduce accumulation in arthropods and insects. Finally, this research reveals the importance of forested areas to short-tailed bats so I recommend to increase the management of landscape plantings in agricultural areas, which surround known bat populations, with bat movements in mind. The bats tracked in this study showed a clear preference for travelling through forest corridors rather than open space, meaning any apparent lack of bat activity in Waipapa may be due to limited access or connectivity. While it is evident that some individuals are happy to travel through such disconnected habitat they were in reasonably low numbers in comparison to the nearby Pikiariki Ecological Area. It may therefore be beneficial to create a continuous corridor, or improve existing fragments, to encourage bat movement between and around Pikiariki and Waipapa.

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Appendix I: Study Area and Location Fixes

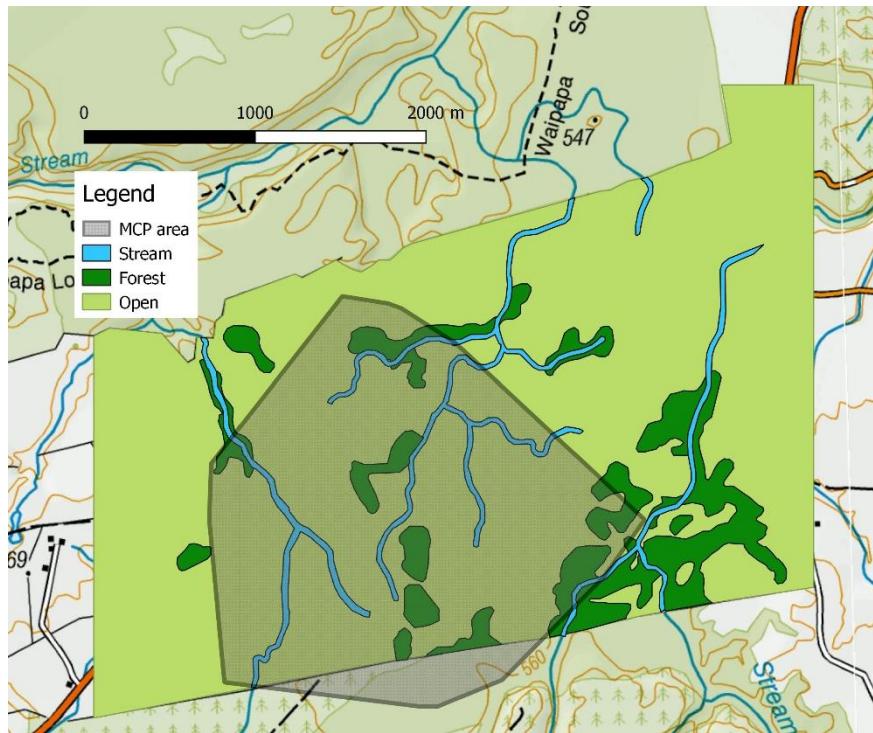


Figure 1: Assigned habitat types on the farmland area between Pikiariki ecological reserve, and Waipapa forest (-38.4805, 175.5875), with dark green showing Forest habitat, Blue representing stream gullies, and light green the remaining open farmland. Also outlined in grey is the 95% minimum convex polygon of all data points defining the area used for analysis.

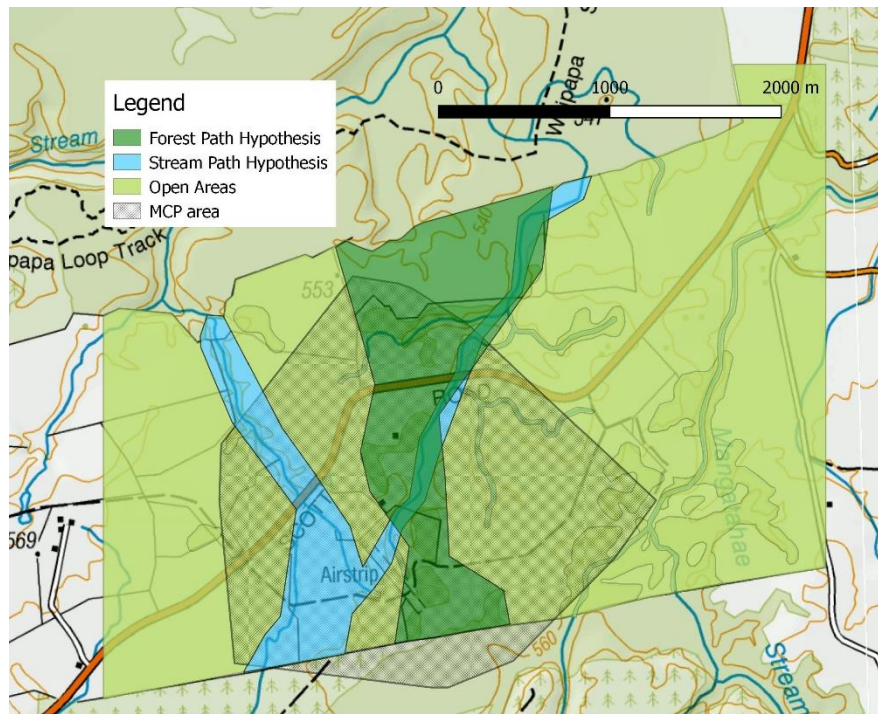


Figure 2: Assigned path types on the farmland area between Pikiariki ecological reserve, and Waipapa forest (-38.4805, 175.5875), with dark green showing Forest path, Blue representing stream gully path, and light green the remaining open farmland. Also outlined in grey is the 95% minimum convex polygon of all data points defining the area used for analysis.

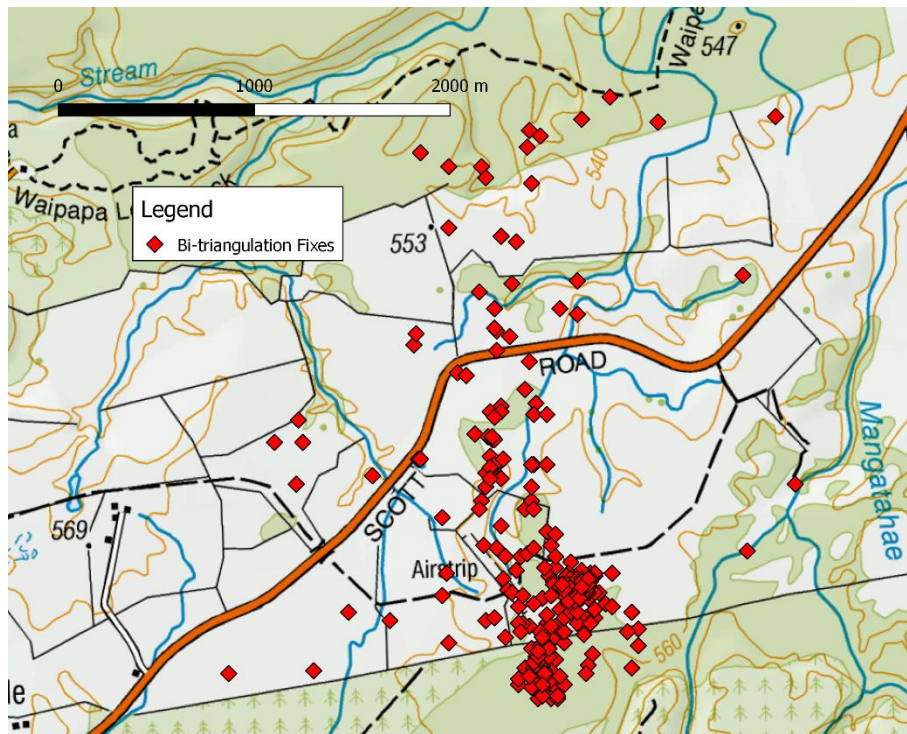


Figure 3: All 302 usable triangulation fixes indicated by red diamonds. The background map shows green forested areas, blue streams, and light grey open areas. State highway 32 (Scott road) is shown as a red line.

Appendix II: Movement Trajectories

Visual trajectories of each individual, in which each tracked night is coded a different colour. For all the following images, solid lines represent approximate travel paths between triangulation fixes, and dotted arrow lines depict predictions of projected trajectories out of receiver range. Projected Trajectories are inferred flight paths based on the direction the individual was already flying, and single bearing records upon loss of signal, but not based on any triangulations.

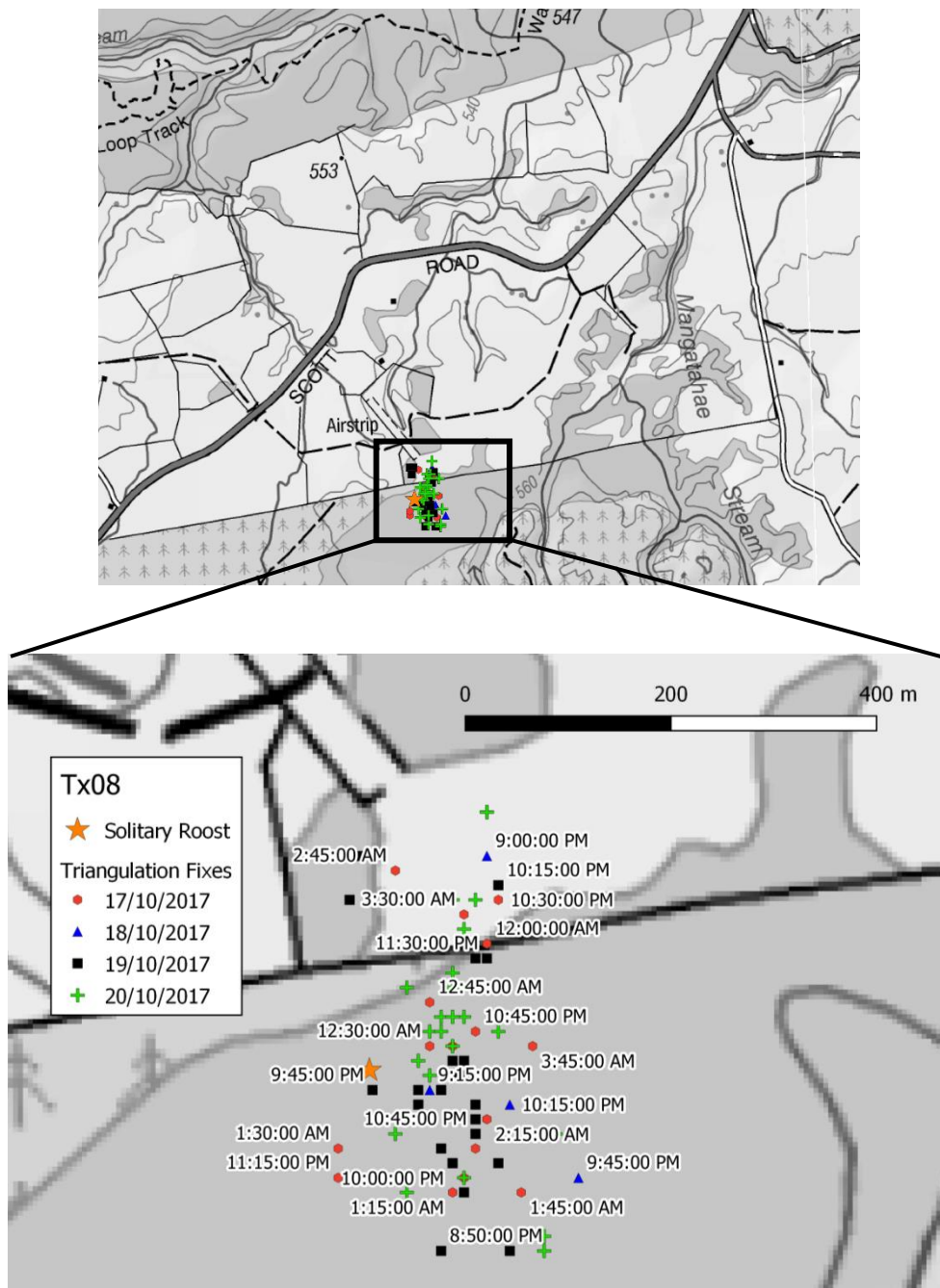


Figure 1: Triangulation points for TX08

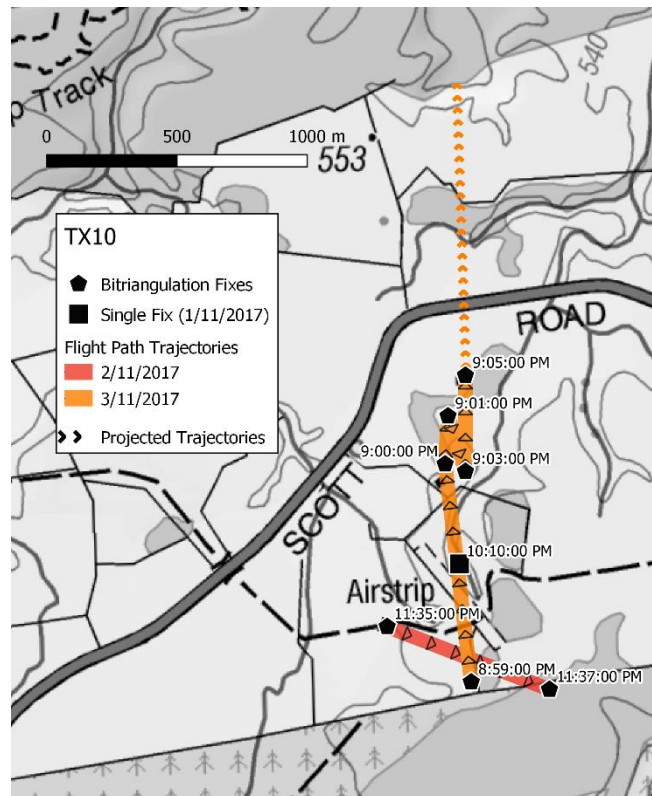


Figure 2: Triangulation fixes and trajectories for TX10

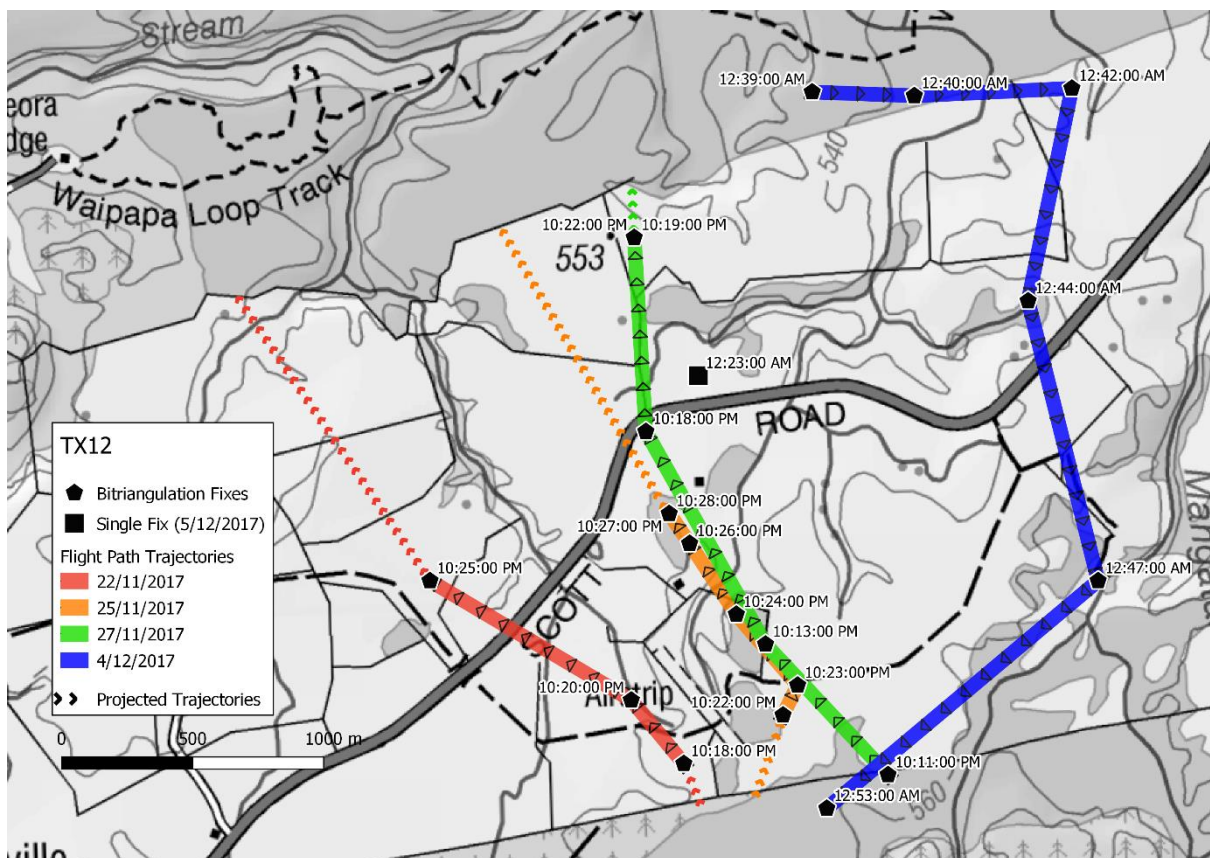


Figure 3: Triangulation fixes and trajectories for TX12

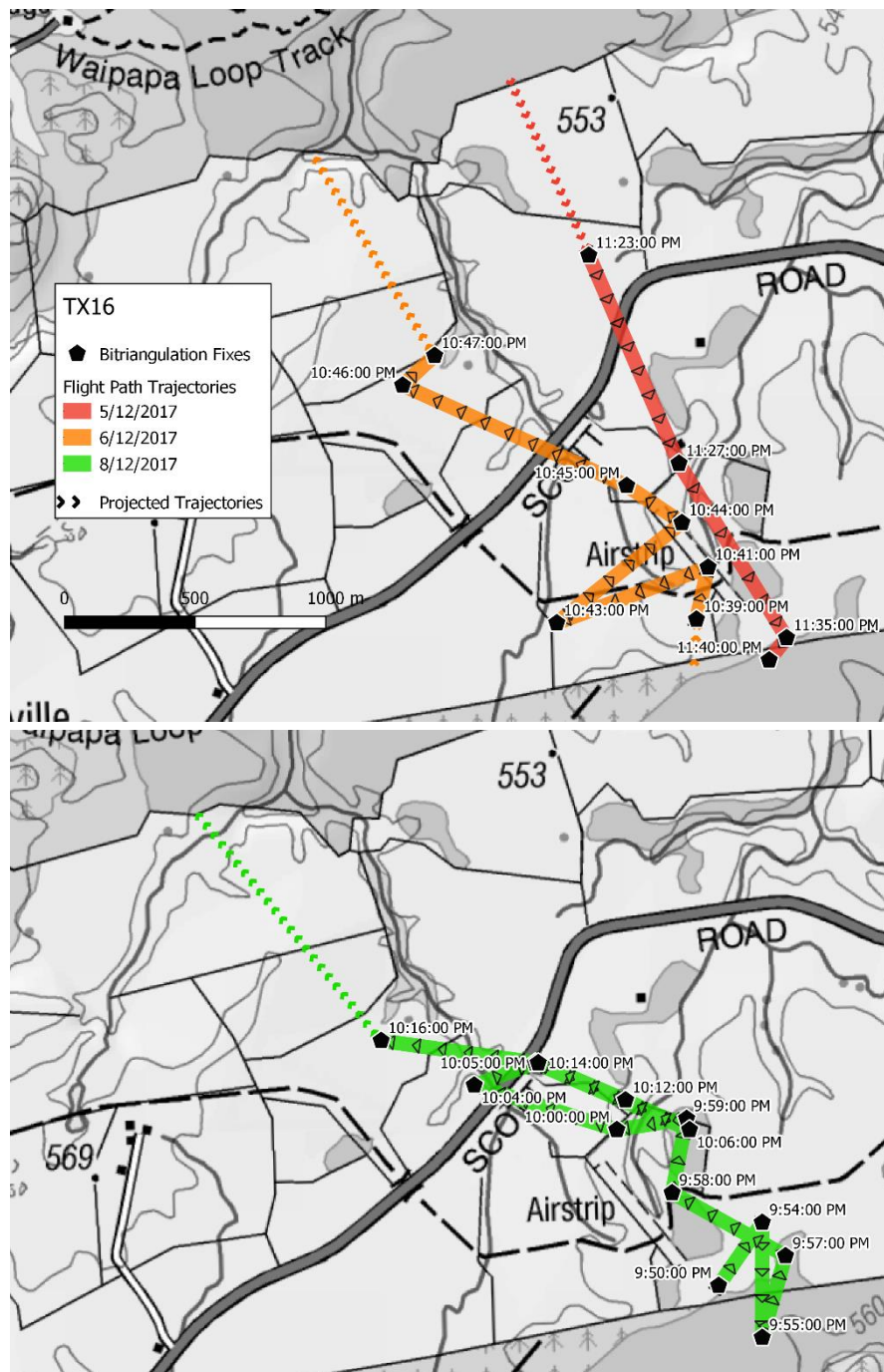


Figure 4: Triangulation fixes and trajectories for TX16

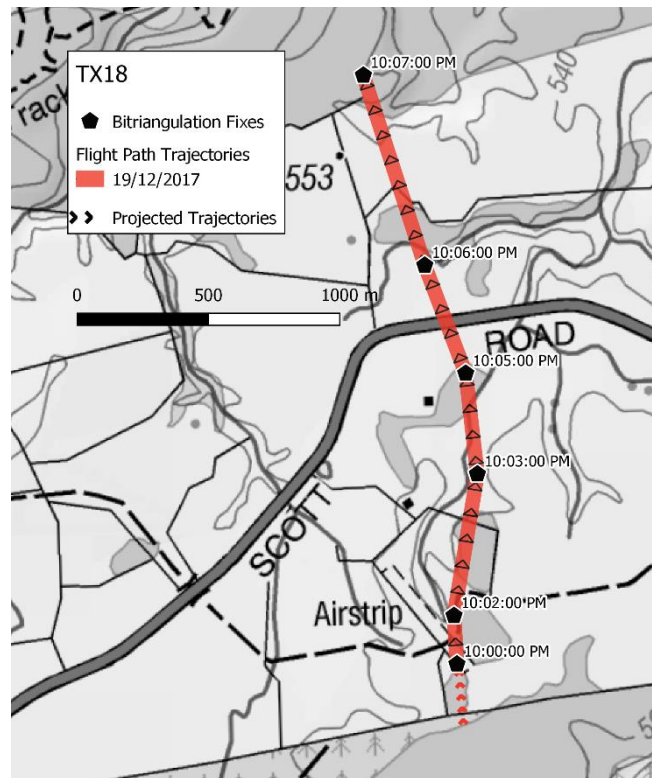


Figure 5: Triangulation fixes and trajectories for TX18

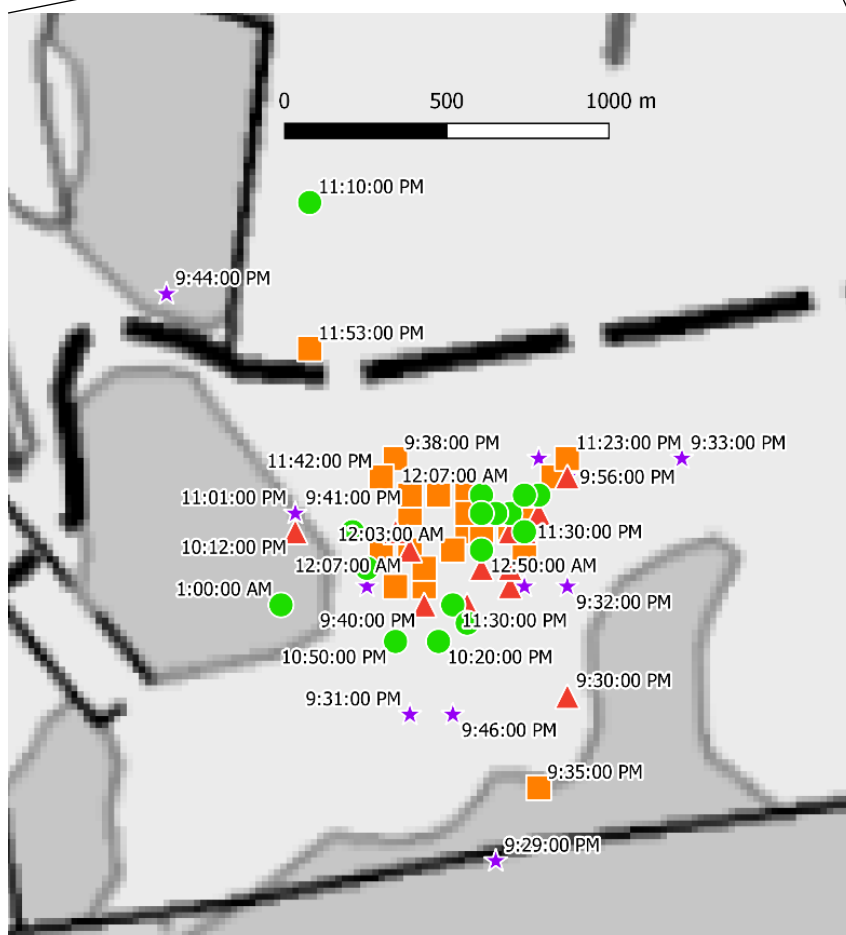
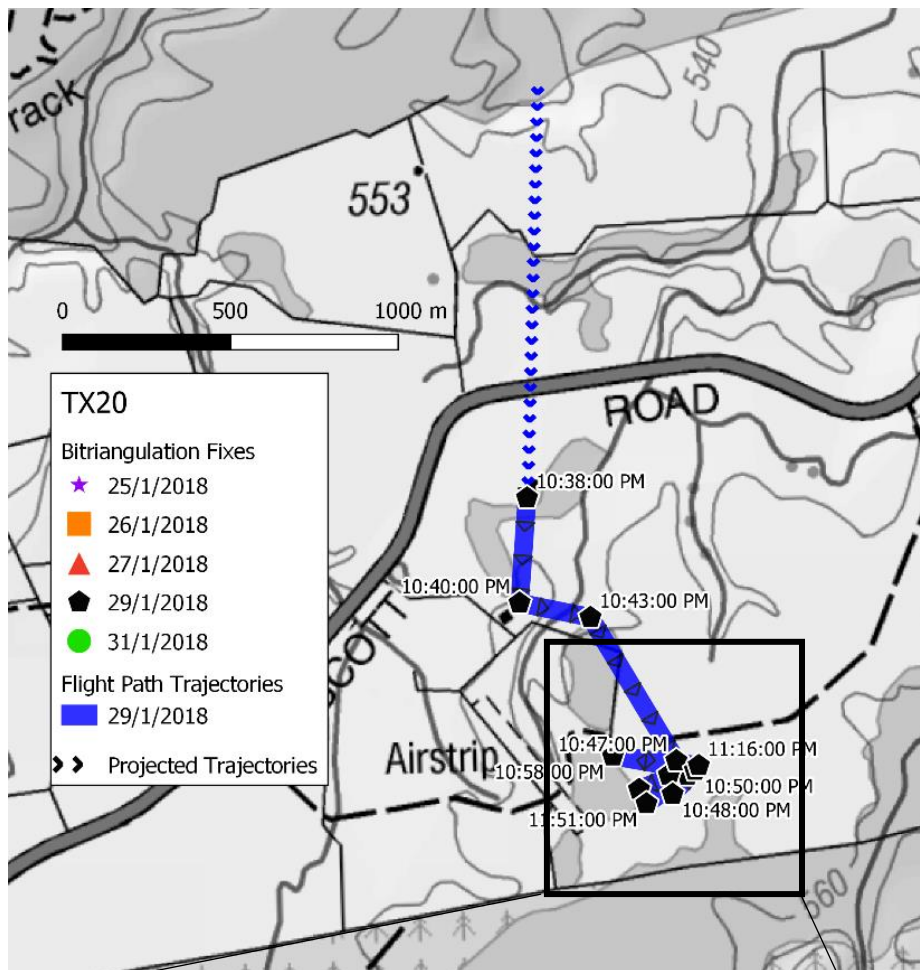


Figure 6:
Triangulation fixes
and trajectories for
TX20

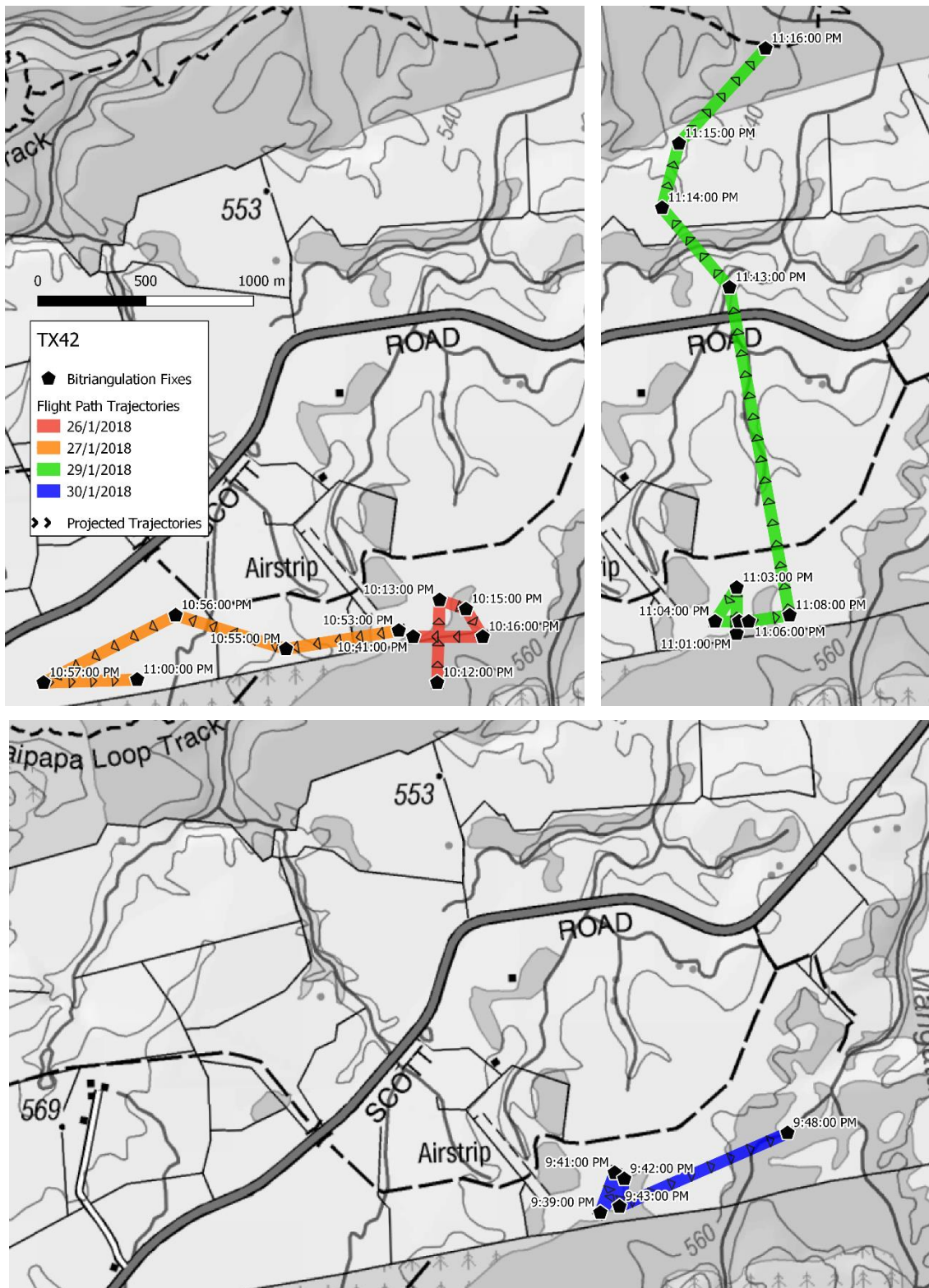


Figure 7: Triangulation fixes and trajectories for TX42

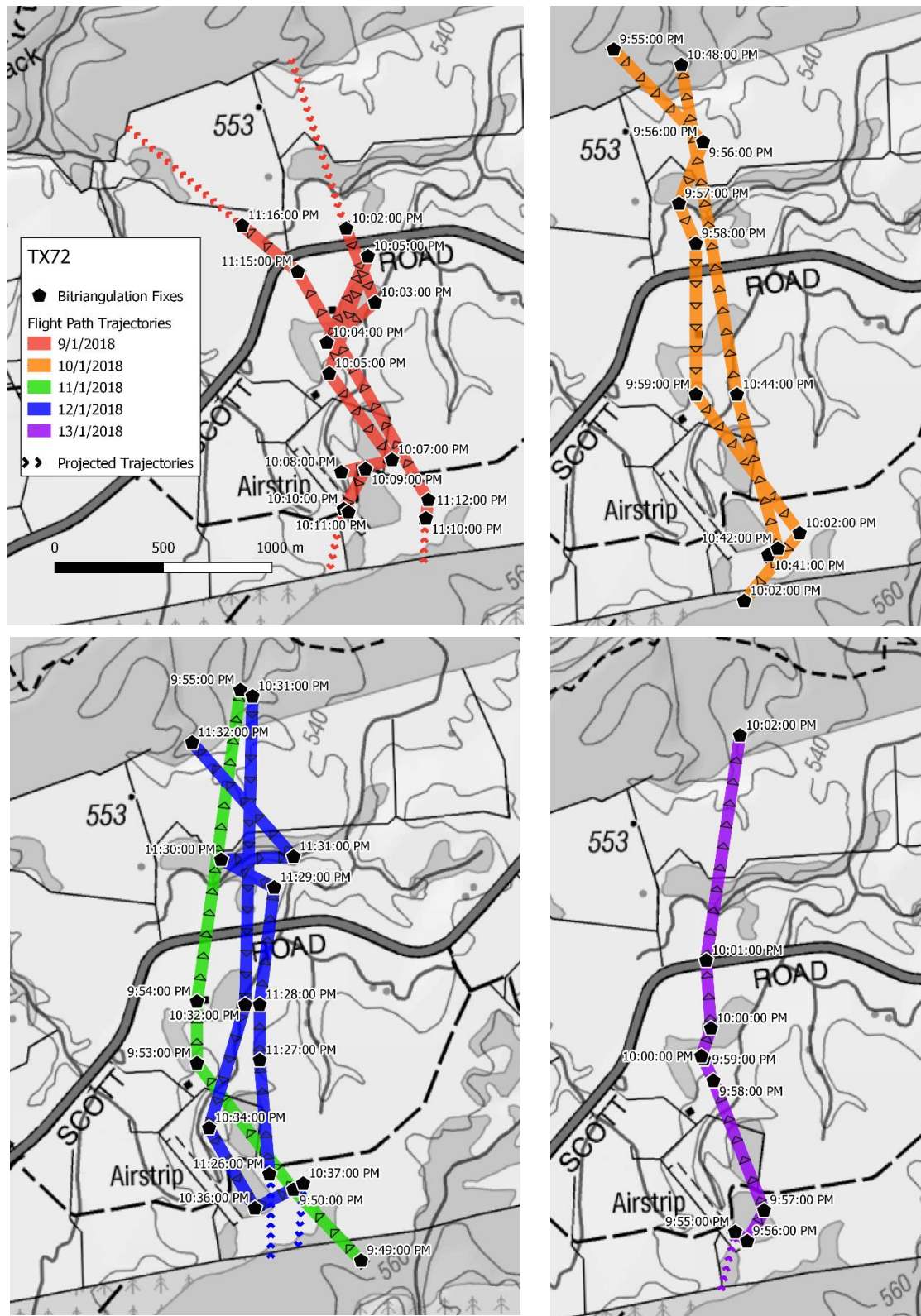


Figure 8: Triangulation fixes and trajectories for TX72

Appendix III: Habitat Type Usage

Table 1: Raw data showing the area of each habitat type utilised hectares (ha_i), and the proportion of each habitat type used (U) by each individual. Total availability (A) and proportionate availability of each habitat type (A_i) are shown. Use ratio is then calculated by U/A_i .

		8	10	12	16	18	20	42	72	Availability (A)
Area used (ha_i)	Forest (ha_f)	1.61	1.41	3.64	3.08	1.36	4.34	2.75	5.56	44.2927
	Stream (ha_s)	0	0.31	0.39	0.46	0.56	0.02	0.42	1.56	21.3023
	Open (ha_o)	1.42	4.99	8.16	13.22	2.91	12.08	9.31	23.64	320.779
										Proportionate Availability (A_i)
Proportion used (U) = ($ha_i / ha_f + ha_s + ha_o$)	Forest	0.531	0.210	0.299	0.184	0.282	0.264	0.220	0.181	0.114603
	Stream	0.000	0.046	0.032	0.027	0.116	0.001	0.034	0.051	0.055091
	Open	0.469	0.744	0.669	0.789	0.602	0.735	0.746	0.769	0.830307

Table 2: Raw data (Table 1) plus 0.5 to allow log transformation of zero value ratios

		8	10	12	16	18	20	42	72	Availability (A)
Area used (ha_i)	Forest (ha_f)	2.11	1.91	4.14	3.58	1.86	4.84	3.25	6.06	44.7727
	Stream (ha_s)	0.5	0.81	0.89	0.96	1.06	0.52	0.92	2.06	21.7823
	Open (ha_o)	1.92	5.49	8.66	13.72	3.41	12.58	9.81	24.14	321.259
										Proportionate Availability (A_i)
Proportion used (U) = ($ha_i / ha_f + ha_s + ha_o$)	Forest	0.466	0.233	0.302	0.196	0.294	0.270	0.232	0.188	0.114603
	Stream	0.110	0.099	0.065	0.053	0.167	0.029	0.066	0.064	0.055091
	Open	0.424	0.669	0.633	0.751	0.539	0.701	0.702	0.748	0.830307

Table 3 Raw data showing the area of each path type utilised hectares (ha_i), and the proportion of each path type used (U) by each individual. Total availability (A) and proportionate availability of each path type (A_i) are shown. Use ratio is then calculated by U/A_i .

		8	10	12	16	18	20	42	72	Availability (A)
Area used (ha_i)	Forest (ha_f)	4.04	4.69	6.83	6.98	4.72	14.76	8.76	26.62	99.82
	Stream (ha_s)	0.00	1.37	0.96	3.31	0.66	0.34	1.05	3.15	71.23
	Open (ha_o)	0.00	0.67	3.12	6.47	0.07	1.68	3.56	3.18	225.22
										Proportionate Availability (A_i)
Proportion used (U) = ($ha_i / ha_f + ha_s + ha_o$)	Forest	1.00	0.70	0.63	0.42	0.87	0.88	0.66	0.81	0.25
	Stream	0.00	0.20	0.09	0.20	0.12	0.02	0.08	0.10	0.18
	Open	0.00	0.10	0.29	0.39	0.01	0.10	0.27	0.10	0.57

Table 4: Raw data (Table 3) plus 0.5 to allow log transformation of zero value ratios

		8	10	12	16	18	20	42	72	Availability (A)
Area used (ha_i)	Forest (ha_f)	4.54	5.20	7.33	7.48	5.22	15.26	9.26	27.12	100.32
	Stream (ha_s)	0.50	1.87	1.46	3.81	1.16	0.84	1.55	3.65	71.73
	Open (ha_o)	0.50	1.17	3.62	6.97	0.57	2.18	4.06	3.68	225.72
										Proportionate Availability (A_i)
Proportion used (U) = ($ha_i / ha_f + ha_s + ha_o$)	Forest	0.82	0.63	0.59	0.41	0.75	0.83	0.62	0.79	0.25
	Stream	0.09	0.23	0.12	0.21	0.17	0.05	0.10	0.11	0.18
	Open	0.09	0.14	0.29	0.38	0.08	0.12	0.27	0.11	0.57