Ecosystem Services Provided by North Island Brown Kiwi (*Apteryx Mantelli*) in Two Horticulture Settings - Vineyards and Kiwifruit Orchards

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Plate 1.1 – Brown kiwi footprints found on The Landing's beach. Photo by author.

"*We only know a tiny proportion about the complexity of the natural world. Wherever you look, there are still things we don't know about and don't understand. There are always new things to find out if you go looking for them.*"

Sir David Attenborough

Abstract

Ecosystem services provide essential benefits to humans from natural ecosystems. Recognising and valuing these services is crucial. By implementing sustainable management practices that balance human needs with biodiversity preservation, we can ensure the long-term health of both ecosystems and people. North Island brown kiwi (*Apteryx mantelli*), an endemic New Zealand bird are nocturnal ground insectivores whose numbers are increasing following conservation management practices. They are now being reported more frequently from human-modified landscapes. This study explores the possible role of the brown kiwi as pest controllers in vineyards and kiwifruit orchards, focusing on its foraging behaviour and habitat use. I collected data using acoustic recorders only in one study site, and camera traps, pitfall traps, and kiwi faeces analysis across four study sites. These methods aimed to investigate their activity pattern, habitat use, diet composition, and the invertebrates' composition in this specific area. Acoustic recorders provide kiwi vocal behaviour, estimate population density, and at the same time, camera traps monitor their movement and habitat preference between orchard and bush areas. Pitfall traps and faecal analysis help to identify available and consumed invertebrate prey for them. I used capture rate calculations, Non-Metric Multidimensional Scaling (NMDS), and Spatial Capture-Recapture (SCR) modelling for statistical analyses. That is to assess kiwi activity, diet overlap between seasons and study sites and estimate population density. I found that they were more active in bush areas, but also used orchards, especially those with dense canopy cover, like Puriri Park. Seasonal changes affected invertebrate availability and their behaviour. Kiwi were most active in summer and less active in winter. Kiwi faeces contained potential orchard pest species, suggesting they may be a potential pest controller. Using predator heat maps made with camera trap data, I found different levels of threat at different locations, with higher numbers of predators closer to the bush area. The spatial capture-recapture model estimated a low kiwi density, which may be due to detection limitations and small sample sizes. It may be necessary to increase the sample size in future studies to reflect the most realistic results. Overall, the findings suggest that habitat characteristics such as canopy cover, soil conditions and surrounding vegetation influence their behaviour and that horticultural landscapes can support kiwi if managed properly. Additionally, my findings show that kiwi use modified landscapes and can inform orchardists on how to make horticultural settings more kiwi-friendly through improved habitat and pest management. Future research should increase the number of orchards used and include more diverse horticultural settings to test the replicability of these findings and their extent. Research could also assess the effectiveness of different orchard management practices on their behaviour. These efforts will support better conservation strategies and promote eco-friendly orchard management in New Zealand.

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CHAPTER ONE

Introduction

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1.1 Ecosystem services

1.1.1 Definition

Ecosystem services are the benefits that humans gain from natural ecosystems. These services are typically categorised into four main types (De Groot et al., 2002; Fisher et al., 2009). Provisioning services, comprising the supply of food, water, and raw materials. Regulating services, including the control of climate, floods, disease, waste, and water quality. Cultural services contain recreational, aesthetic, and spiritual benefits. Finally, supporting services include soil formation, photosynthesis, and nutrient cycling. Ecosystem services are crucial for human survival and well-being, as they support the functioning of ecological processes that sustain life on earth (Daily, 1997; Haines-Young, 2010). However, human activities often disrupt these essential services, leading to a decline in ecosystem health and a reduction in nature's benefits. For instance, pesticides are widely used in pastoral and horticulture to improve crop quality and yields and reduce management costs. While effective in maintaining crop quality, these chemical pesticides can have negative effects on natural ecosystems (Sánchez-Bayo, 2019). The widespread use of neonicotinoid pesticides has been linked to declines in pollinator populations, such as bees, which reduces pollination services essential for both wild ecosystems and agricultural productivity (Potts et al., 2016). Therefore, it is critical to understand and value ecosystem services. By developing sustainable management practices that balance human needs with the protection of biodiversity and natural resources, we can ensure the long-term health of both ecosystems and human populations. One approach to achieving sustainable management practices is by intercropping companion plants that mutually benefit each other. Putting these plant species together can lower management costs and potentially increase income for the additional plant species (Lithourgidis, 2011). Additionally, using biocontrol with non-chemical pest management methods can further reduce the environmental impact of agriculture (Gurr, 2003; Heimpel, 2017). Birds are a prominent example of natural enemies of pests and make significant contributions to biological control in agricultural ecosystems. For instance, Mols and Visser (2007) found that Great tits (*Parus major*) can reduce caterpillar density in apple orchards by up to 50%, leading to increased fruit yield and decreased need for chemical pesticides. However, neither this study nor that of Karp (2014) directly compares the effectiveness of bird control with chemical insecticide control. Nonetheless, the findings highlight the dual benefit of enhancing bird populations: promoting crop productivity while reducing environmental impact.

1.1.2 Examples of Ecosystem Services in Agriculture

In agriculture, the ecosystem services provided by biological organisms play a crucial role in enhancing productivity and sustainability. For instance, pollination by bees and other insects is essential for the production of many fruits and vegetables, significantly increasing agricultural yields (Ricketts et al., 2008; Klein et al., 2007). In biological pest control, natural predators or parasites can be used to manage pest density. In today's society, the use of pesticides is very common (Aktar et al., 2009). Using biological pest control can reduce the need for chemical pesticides in these areas, potentially increasing crop yields and value, lowering pesticide costs in management, and resulting in healthier products and maintaining the surrounding ecosystems better (Sharma et al., 2019). This creates a win-win situation, benefiting both economically and in terms of environmental conservation. Moreover, many species can provide essential ecosystem services, including insects and mammals such as bats (Boyles et al., 2011; Maas et al., 2013). However, in this thesis, I will focus on the ecosystem services provided by birds in horticulture. Birds can offer ecosystem services such as pest control, seed dispersal, pollination, fertilisation, changing soil structure, and helping prevent plant diseases (Şekercioğlu, 2006; Wenny et al., 2011). Understanding and effectively utilising these services provided by biological organisms in agriculture can lead to more sustainable and efficient agricultural systems. In New Zealand, native species like the kiwi (*Apteryx* spp.) could play an important role in natural pest control. As a larger bird, the kiwi could be more efficient at reducing pest populations compared to other native insectivorous species like fantail (*Rhipidura fuliginosa*). Utilising the kiwi as a pest controller can reduce management costs for pest control and offer opportunities for environmental education and increase public awareness of this iconic species. By integrating native species into pest management strategies, New Zealand can simultaneously promote biodiversity conservation and sustainable agriculture. This thesis will focus on exploring the various ecosystem services provided by North Island brown kiwi within horticultural settings, emphasising their significance in pest control and overall ecosystem health.

1.1.3 Importance of Insectivorous Birds

Native birds can have both negative and positive impacts on crops. For example, in the viticulture industry, frugivorous birds often cause significant damage to fruits causing substantial economic losses (Gray, 1991; Nelson, 1990; Porter, 1992). However, insectivorous birds do not damage grape harvests and can provide valuable ecosystem services, such as pest control in horticultural settings (Barbaro et al., 2017). Increasingly, people are recognising the important ecological functions that birds provide. Birds' ability to fly allows them to connect different habitats and provide a variety of ecological services. As some of these services have economic value, humans are beginning to invest more resources into understanding the benefits birds provide (Şekercioğlu et al., 2019; Wenny et al., 2011). Birds impact pest populations and density, not only through direct predation but also by stimulating defensive behaviours in pests (Kollross et al., 2023). The fear of predation can cause pests to alter their behaviour, morphology, physiology, or development to avoid being eaten (Evan, 1990). These changes may involve increased energy costs, such as enhancing mating success or altering migratory behaviour. However, these changes can also increase the pests' vulnerability to their predators. The energy invested in these behavioural adaptations can indirectly affect pest populations and densities (Philpott et al., 2009; Preisser et al.,2005). These are the impacts and effects brought by birds. Moreover, pest populations and densities are major factors causing yield reduction, so bird predation can play a crucial role in protecting farmland and orchards.

Several studies have pointed out that birds can significantly reduce pest populations in economically important crops like apples, coffee, and grapes (Barbaro et al., 2017; Karp et al., 2013; Mols and Visser, 2002). In Mols and Visser (2002) study, great tits were found to be more effective than pesticides at controlling caterpillars in apple orchards (*Malus domestica*). Their presence greatly reduced leaf damage and plant death. Removing caterpillars early led to less crop damage. That means delayed removal caused more harm, lowering crop yields and wasting early farming efforts. The researchers recommended placing nest boxes in orchards to provide more breeding sites for great tits. This should help young birds maturing faster and to reduce the economic losses caused by caterpillars. This pest control method is cheaper and more effective than using pesticides, which caterpillars can develop resistance to over time. Overall, the presence of great tits increased crop yields by 60%, showing the advantages of using birds for sustainable pest management. Allowing and encouraging this ecosystem service by great tits is not only less expensive in the short term, but avoids issues with pesticide resistance, thus reducing the need for pesticide development and pesticide accumulation in the environment. Likewise, Karp et al. (2013) found that native birds were more effective than pesticides in reducing the infestation of coffee plants by coffee berry borer beetles (*Hypothenemus hampei*). The presence of birds lowered infestations by 50% and allowed a reduction in pesticides used. This ecosystem service economic benefit to the farmers was equivalent to an average annual income in Costa Rica. In the study, the authors recommend the development of forests in or around coffee plantations to encourage birds to visit the orchards. Furthermore, studies have shown that the presence of surrounding forests can significantly benefit coffee production by enhancing the pollination services of local insects. Several studies have shown that areas close to natural forests can increase the abundance and diversity of pollinators, thereby improving fruit yields in coffee plantations (Aristizábal et al., 2025; Caudill et al, 2017; González-Chaves et al., 2020). In another example, Wearing (1992) found that where present, silvereyes (*Zosterops lateralis* L.) in New Zealand, destroyed about 53% of the overwintering codling moth larvae (*Cydia pomonella* L.) a pest of apples. Whereas in areas without silvereyes, the larvae mortality rate was just 5% (Preisser et al., 2005).

Ecological engineers are organisms that directly or indirectly control the availability of resources by causing changes in the physical state of biological or non-living materials (Jones et al., 1997). In New Zealand, the North Island brown kiwi, approximately the size of a domestic chicken, could play a significant role in pest control, soil fertilisation, seed dispersal, and soil structure improvement. Research has shown that brown kiwi regularly forage in pasture environments (Cunningham & Castro, 2011; Dixon, 2015; Watt, 1971). Their diet primarily consists of invertebrates, including earthworms, beetles, snails, and insects, which they detect and consume by probing the soil with their long beaks. This foraging behaviour is unlikely to cause damage to crops, as their feeding habits do not involve plant material. While past studies have focused on their foraging behaviour in forests, there is a lack of research on the North Island brown kiwi's potential benefits in agricultural systems. Using the kiwi as a natural pest controller could lower management costs and provide additional opportunities for environmental education and public awareness of this New Zealand national icon species. Integrating native species like the North Island brown kiwi into pest management strategies could promote biodiversity conservation and support sustainable agriculture in New Zealand. This study explores the potential role of the North Island brown kiwi as a pest controller in the vineyard and kiwifruit orchard environments.

1.2 Study Species

1.2.1 Classification

Despite the kiwis' iconic status among New Zealand's unique wildlife, our knowledge of these species, like that of other species, remains a constant process of discovery (Germano et al., 2018). Modern genetic analyses have identified five recognised species of the genus *Apteryx*, including the North Island brown kiwi, southern tokoeka (*A. australis*), okarito kiwi (*A. rowi*), great spotted kiwi (*A. maxima*), and little spotted kiwi (*A. owenii*) (Weir et al. 2016). Different kiwi species and populations exhibit variations in their survival strategies, including foraging strategies, mating systems, and breeding strategies (Sales, 2005).

1.2.2 Conservation

The North Island brown kiwi is the most common of the five extant kiwi species. The estimated total number of the North Island brown kiwi is about 25,100 individuals (Germano et al. 2018), and they are also one of the most studied species (Germano et al. 2018; Robertson et al. 2016). Human settlement in New Zealand brought significant environmental changes, including large-scale deforestation, which has reduced the original forest cover to just 22% (Mills & Williams, 1979). This deforestation dramatically decreased the available habitat for the North Island brown kiwi, limiting their chances of survival (Stevens et al., 1995). For thousands of years, the North Island brown kiwi evolved in the absence of mammalian predators, developing unique traits suited to a mammalian predator-free environment. However, the arrival of humans introduced a range of non-native mammals that now pose substantial threats to the kiwi's survival. These introduced mammals include predators such as stoats (*Mustela erminea*), ferrets (*Mustela furo*), feral cats (*Felis catus*), and domestic dogs (*Canis lupus familiaris*), as well as competitors like common brushtailed possums (*Trichosurus vulpecula*) and three species of rats (*Rattus rattus*, *R. norvegicus*, and *R. exulans*) (Germano et al., 2018; Robertson et al., 2011; Sales, 2005). The kiwi's survival strategies, shaped over generations in predator-free conditions, are ill-suited for coexistence with these invasive species, leaving the kiwi particularly vulnerable. This combination of habitat loss and the pressures introduced by new predators and competitors underscores the significant challenges facing the North Island brown kiwi today.

Brown kiwi have long lifespans and diverse mating systems and breeding strategies (Undin & Castro 2021). However, their populations face significant challenges due to extremely low survival rates during the egg and chick stages in many predator-invaded sites (McLennan et al., 1996; Robertson et al., 2011). As a result, the survival of adult birds is crucial for maintaining population numbers, as adult mortality has a much greater impact on population recovery and growth than the frequent predation of chicks (Robertson et al., 2011). Feral cats and stoats are the two main predators of kiwi chicks, they often prey on smaller, lighter-weight chicks (McLennan et al., 1996). Stoats have a high predation success rate of 60% on kiwi chicks (McLennan et al., 1996). Adult kiwi, which typically have a higher survival rate due to their size, are still killed by dogs (Pierce & Sporle, 1997) and ferrets (McLennan et al., 1996; Pierce & Westbrooke, 2003). Moreover, nearly half (47%) of New Zealand's total land area has been converted to pasture (Blackwell, 2005). Most native lowland fauna in New Zealand are adapted to live in forest ecosystems (Stevens et al. 1995). Luckily, the North Island brown kiwi can use a variety of habitats including swamps, pasture, scrub, and forests (Cunningham & Castro, 2011; Dixon, 2015; Miles et al., 1997).

In 1991, New Zealand initiated a kiwi recovery plan aimed at preventing all five kiwi species from going extinct and this plan has been revamped several times to account for changes in kiwi populations (Germano et al. 2018; Holzapfel et al., 2008; Robertson, 2004). These plans focused on improving predator control, raising chicks in captivity to protect them during their most vulnerable life stages, and establishing new populations in predator-proof sanctuaries and later in predator-controlled mainland sites. Key initiatives, such as Operation Nest Egg (ONE), were also developed to support these goals and are discussed in detail in subsequent sections. Predators like feral cats, stoats, ferrets, and dogs, remain significant threats to kiwi populations, necessitating ongoing management efforts. This threat is particularly severe during warmer summers when rabbit populations increase, providing abundant food for ferrets and enabling them to breed more frequently, producing more kits. Stoats are active during the day when kiwi are most vulnerable, and are challenging to trap, further complicating predator management efforts. Possums and rats destroy habitats and compete for food resources with native birds including kiwi (Shapiro, 2005). They also chase birds off their nesting burrows (Jones et al., 2008). In areas with intensive predator control, kiwi hatching success rises to 50-60%, highlighting the importance of managing these predators to protect kiwi populations (Department of Conservation [DOC], 2020). Operation Nest Egg (ONE) is a key conservation tool that significantly improves the survival rate of kiwi chicks (Colbourne et al., 2005). In the wild, without introduced mammal' predator control, roughly 5% of chicks reach adulthood, but through ONE, 65% of chicks survive. This program involves removing kiwi eggs and chicks from their burrows and raising them in captivity until they are large enough to fend for themselves. The chicks are then returned to their original population to preserve genetic diversity. The process has also contributed to a deeper understanding of kiwi behaviour and breeding, which has informed ongoing conservation efforts. Kōhanga Kiwi is a kiwi repopulation strategy led by the corporate-sponsored ‘Save the Kiwi’ programme, and they aim to increase the national Kiwi population by 2% annually. It collaborates with “Operation Nest Egg” to relocate kiwi chicks into predator-free kōhanga sites. The chicks grow, find mates, breed, and live without the threat of predators in these protected environments. This strategy is focused primarily on the North Island brown kiwi, providing a safe space to help increase their population numbers and maintain their long-term survival (*Save the Kiwi*, n.d.). Several kiwi sanctuaries were established to protect kiwi populations within their habitats (Robertson, 2004). In addition, in 2016, the New Zealand government launched a new proposal to make the country predator-free by 2050. The goal of this project is to eliminate rats, possums, and stoats by 2050 (Parliamentary Commissioner for the Environment, 2017). This initiative would reduce the ongoing threats faced by the North Island brown kiwi. They also hope to raise public awareness and highlight the importance of biodiversity conservation. Furthermore, there has been a significant increase in community-led restoration projects focusing on planting native vegetation and predator control, particularly in regions such as Northland, where these efforts have been highlighted as vital for ecological restoration

(Peters et al., 2015; McFarlane et al., 2024). The general public are becoming increasingly willing to recognise the importance of protecting these unique native species in their own backyards in New Zealand.

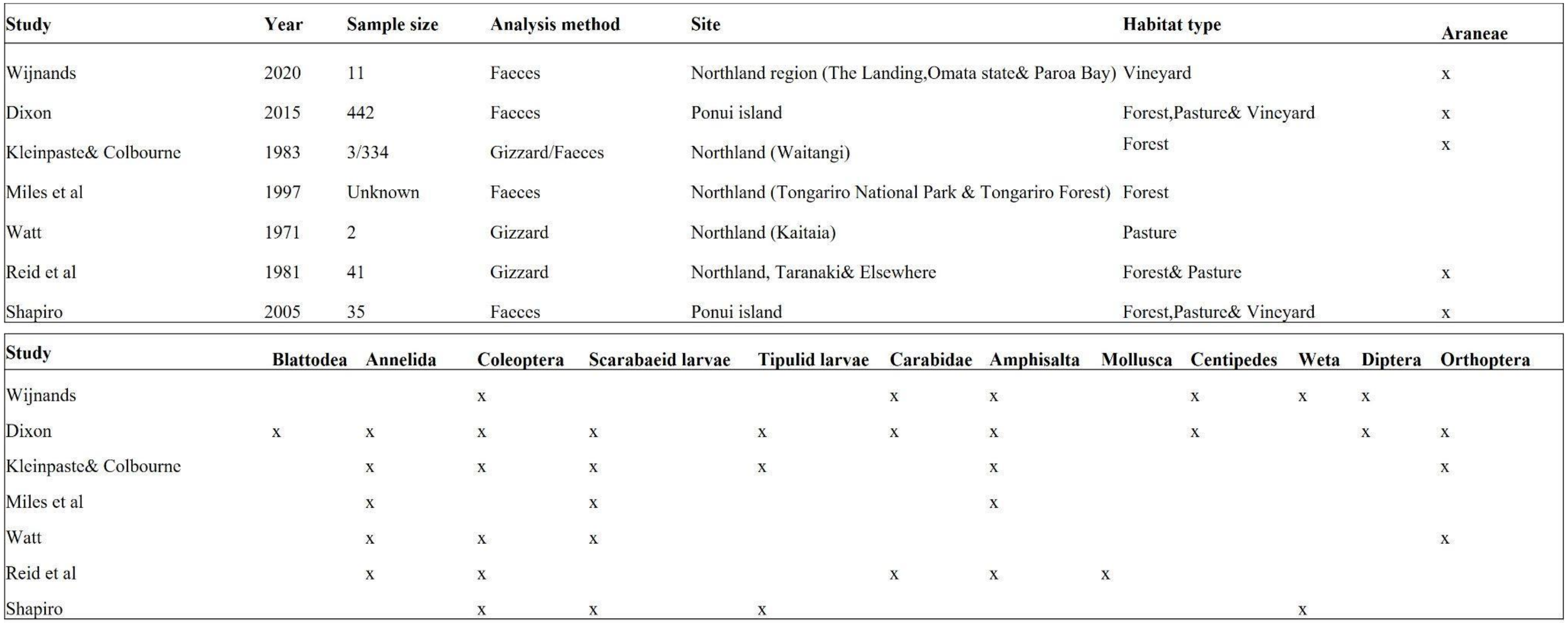
1.3 North Island Brown Kiwi Diet

The North Island brown kiwi's diet includes both vertebrate and invertebrate species. Several studies (Table 1.1) have also documented the presence of plant material in the stomach contents of dead North Island brown kiwi, and it is generally thought that seeds and other plant material are used in the kiwi gizzard to break down food (Bull,1959; Gurr, 1952; Reid et al.1982; Watt, 1971). However, there is no conclusive evidence of the specific role of vegetable matter in kiwi digestion.

Numerous invertebrate groups have been identified in the faeces (Dixon,2015; Kleinpaste& Colbourne, 1983; Miles et al. 1997; Shapiro, 2005; Wijnands, 2020) and stomach contents of kiwi (Chan, 1999). Notably, New Zealand has an abundance of annelid worms (Lee, 1959). Diet analyses using gizzard contents have revealed that annelid worms are present in 94% of the kiwi examined, and Coleoptera in 90% of 50 gizzards examined. Additionally, large numbers of cicada nymphs (*Amphisalta*) and Melolonthinae beetles (*Odontria*), both adults and larvae, were found in the stomachs of kiwi (Reid et al., 1982). These insects are abundant year-round and are believed to be an important part of the kiwi’s diet. Other studies have identified between 13 and 16 different invertebrate groups contributing to the kiwi’s diet, with the most commonly identified taxa being Annelidae, Hemiptera, Araneae, and Scarabaeidae (Colbourne & Powlesland, 1988; Dixon, 2015). Dixon’s study (2015) identified 16 invertebrate groups, with Coleoptera accounting for 89.3% of the total invertebrates found in the faeces. Hemiptera and Diptera were also present in significant numbers. Cicada nymphs and Scarabaeidae larvae, which are important soil-dwelling invertebrates, were observed as key components of the brown kiwi’s diet by Kleinpaste & Colbourne (1983), Miles et al. (1997) and Dixon (2015). Certain invertebrates may be consumed seasonally, depending on their life stage. For example, in Colbourne and Powlesland’s (1988) study, nymphs were eaten in most months, but more frequently in summer, when they are close to the soil surface, before emerging into adults later in the year. Watt (1971) provided further evidence of brown kiwi forage in pasture, finding three species, cricket *Teleogryllus commodus*, rove beetle *Thyreocephalus chloropterus*, and scarab beetle, *Heteronychus arator*—in the gizzard of a deceased kiwi. These species are typically found in open areas such as farmland, indicating that kiwi also utilise pasturelands for foraging. As exotic plantations, farmlands and orchards have expanded they may now become increasingly important foraging grounds for the brown kiwi, potentially enhancing food availability and foraging efficiency (Cunningham & Castro, 2011).

Although past studies suggest that forested environments are the preferred habitat for the brown kiwi, these habitats have been significantly degraded and reduced due to human activities and land development (Miller, 1995). It remains uncertain to what extent predator control has influenced kiwi movement into pastures and orchards, and further research is needed to clarify this behaviour.

Table 1.1 Studies of the North Island brown kiwi Diet



Study	Year	Sample size	Analysis method	Site	Habitat type	Araneae
Wijnands	2020	11	Faeces	Northland region (The Landing,Omata state& Paroa Bay)	Vineyard	x
Dixon	2015	442	Faeces	Ponui island	Forest,Pasture& Vineyard	x
Kleinpaste& Colbourne	1983	3/334	Gizzard/Faeces	Northland (Waitangi)	Forest	x
Miles et al	1997	Unknown	Faeces	Northland (Tongariro National Park & Tongariro Forest)	Forest	
Watt	1971	2	Gizzard	Northland (Kaitaia)	Pasture	
Reid et al	1981	41	Gizzard	Northland, Taranaki& Elsewhere	Forest& Pasture	x
Shapiro	2005	35	Faeces	Ponui island	Forest,Pasture& Vineyard	x

Study	Blattodea	Annelida	Coleoptera	Scarabaeid larvae	Tipulid larvae	Carabidae	Amphisalta	Mollusca	Centipedes	Weta	Diptera	Orthoptera
Wijnands			x			x	x		x	x	x	
Dixon	x	x	x	x	x	x	x		x		x	x
Kleinpaste& Colbourne		x	x	x	x		x					x
Miles et al		x		x			x					
Watt		x	x	x								x
Reid et al		x	x			x	x	x				
Shapiro			x	x	x					x		

1.4 Behaviour of North Island Brown Kiwi

The North Island brown kiwi shows unique behavioural adaptations that are closely related to its nocturnal lifestyle and ecological niche (Colbourne et al., 2005; Holzapfel et al., 2008). Being primarily active at night, the brown kiwi's nocturnal behaviour may help reduce competition with diurnal species for resources such as invertebrates. However, this behaviour does not necessarily reduce predation risk from introduced mammalian predators, such as stoats and ferrets, which are also largely nocturnal. Instead, these nocturnal strategies likely evolved in the absence of mammalian predators, before their introduction to New Zealand, as an adaptation to reduce competition and predation risks from native avian predators. Further research is needed to clarify the effectiveness of these behaviours in the current environment with introduced predators.

One of the most remarkable adaptations of the North Island brown kiwi is its highly developed sense of smell together with an acute sense of touch. Unlike other birds that rely on visual or auditory cues for foraging, the kiwi's olfactory and tactile capabilities allow it to find food sources hidden within the forest floor (Castro et al. 2010; Cunningham et al., 2009, 2013). These senses are crucial for detecting invertebrates such as earthworms, beetles, and larvae, often hidden under leaf litter or soil layers. Their long, sensitive beaks are effective tools for probing the ground in complete darkness, helping to discover and extract these hidden food resources (Cunningham et al., 2009). The uneven distribution of food resources in forest ecosystems necessitates a systematic foraging strategy by the North Island brown kiwi. The kiwi utilises a slow and deliberate foraging method, probing the forest floor with its highly sensitive bill. This technique allows the kiwi to detect invertebrates and other food sources hidden beneath the soil or leaf litter (Cunningham & Castro, 2011). The bird's foraging behaviour is primarily guided by its sense of touch and smell, rather than sight, which is particularly advantageous in the low-light conditions of its nocturnal activity (McLennan et al., 1996). This behaviour highlights the kiwi’s adaptability to resource availability. They adjust foraging locations, probing depth, and activity timing based on prey abundance, enabling survival in both native and altered habitats (Colbourne& Kleinpaste, 1983; Robertson et al., 2011). This flexibility is crucial in fragmented landscapes affected by human activity and environmental changes (Taborsky & Taborsky, 1995).

The vocalisations of the North Island brown kiwi are likely to play a vital role in its social and territorial behaviour, especially during the breeding season (Colbourne & Kleinpaste, 1983). These calls are possibly used to establish territory, attract mates, and/or avoid predators. As nocturnal birds, their calls are heard at night. Males produce a high-pitched whistle, while females produce low-frequency, raspier calls (McLennan et al., 1996). These differences may help distinguish gender roles in communication and may aid in mate identification during courtship. Additionally, duets between males and females have been heard. This may strengthen pair bonds and coordinate joint territorial defence (Corfield et al., 2008).

Kiwi calls are most frequent during the breeding season, and researchers have suggested that calls play a critical role in defending territory by allowing individuals to establish and maintain territorial boundaries without confrontation (Colbourne & Kleinpaste, 1984). However, habitat changes, such as deforestation and agricultural expansion, alter the acoustic environment and affect the kiwi's vocal behaviour. Dent and Molles (2015) suggested that habitat fragmentation and human noise pollution may interfere with communication, potentially making it more difficult for them to find mates and defend territories, thereby affecting population dynamics. While direct evidence of this phenomenon in other kiwi spp. is limited, studies on other bird species indicate that anthropogenic noise can disrupt communication, leading to challenges in mate attraction and territory defence.

Cofield et al. (2011) provided evidence for an auditory fovea in brown kiwi, an adaptation that enhances their ability to detect specific sound frequencies. This increased auditory sensitivity would enable kiwi to navigate and communicate more efficiently in low-light, ground-dwelling environments, by compensating for their reduced reliance on vision (Martin et al.). The kiwi's specialised hearing system may play a crucial role in increasing the efficiency of vocalisations and helping to maintain social and territorial structures (Miles, 1992). This adaptation, along with their vocal behaviour, highlights the importance of auditory mechanisms in kiwi survival and reproductive success.

In addition, kiwi calls are often used in conservation efforts as a non-invasive way to monitor populations. Call surveys are an effective method of estimating kiwi populations and assessing the success of predator control programs (Dent, 2013; Robertson, 2004). By recording and analysing kiwi calls, researchers can track population trends and gain valuable insights into kiwi behaviour in different habitats (Robertson, 2004; Undin & Castro, 2022). Understanding the vocalisations and auditory adaptations of the North Island brown kiwi is essential for developing effective conservation strategies and ensuring the species' long-term survival. Research indicates that kiwi possess specialised auditory systems, including a basilar papilla with a higher proportion of short hair cells, suggesting an adaptation for high-frequency hearing. This specialisation may aid in detecting conspecific calls and environmental sounds, enhancing their ability to navigate and forage in nocturnal environments (Corfield et al., 2012). Moreover, the distinct vocal patterns of male and female kiwis, characterised by high-frequency components ranging from 2 to 6 kHz, play a crucial role in communication and mate recognition. Analysing these vocalisations provides insights into individual identification and social interactions within kiwi populations (Corfield et al., 2011). By integrating knowledge of kiwi auditory physiology with behavioural studies, conservationists can develop targeted management practices. For instance, deploying acoustic monitoring tools can effectively track population dynamics and inform habitat protection efforts, thereby contributing to the preservation of this iconic species.

1.5 North Island Brown Kiwi in Agriculture

The face of New Zealand has changed dramatically due to human activities. The expansion of agriculture has led to a dramatic reduction in forested areas. This has significantly altered the North Island brown kiwi's habitat. These forests have been transformed into pastures, farmlands, and orchards. These changes created new challenges for the species and raised questions about its ability to adapt and survive in an increasingly changed landscape. By consuming invertebrates such as beetles, larvae, and other soil-dwelling organisms, kiwi may help control pest populations that could otherwise impact crop productivity. Watt (1971) demonstrated that the North Island brown kiwi is capable of foraging in pasturelands. This was shown through the discovery of several insect species, such as *Teleogryllus commodus, Thyreocephalus chloropterus,* and *Heteronychus arator,* in the gizzard of a deceased kiwi. These species are typically associated with open areas like farmlands. This finding indicated that the North Island brown kiwi was using these new environments to forage and used the available resources in pasture. Cunningham and Castro’s observations demonstrated that the North Island brown kiwi is not strictly confined to forest environments but is also utilising pastures with suitable soil conditions, including softer soil and leaf litter (Cunningham & Castro, 2011; Dixon, 2015). This aligns with earlier findings by Colbourne and Kleinpaste (1983) who documented the kiwi's preference for moisture-rich soil, which supports a high density of invertebrates, a crucial food source for the species. Their research suggests that soil texture and organic content play a more significant role in kiwi foraging behaviour than habitat type alone. Dixon (2015) further emphasised that kiwi adapt their foraging strategies based on soil conditions, demonstrating their ability to exploit modified landscapes if key foraging requirements are met. While moisture-rich soil is traditionally associated with forest environments, Cunningham and Castro (2011) observed that kiwi are now utilising pastures with suitable soil conditions, including softer soil and leaf litter (Dixon, 2015). This behaviour is consistent with their ecological role as soil engineers, where their probing and foraging activities help regulate soil invertebrate populations and aerate the soil (Gibbs, 2006).

Brown kiwi have also been observed on the edges of orchards and vineyards, where they can find shelter and food sources (Taborsky & Taborsky, 1995). Studies in areas with mixed-use landscapes (including horticultural crops) show that kiwi can thrive in fragmented habitats if there is adequate cover and food availability (Innes et al., 2010). These findings suggest that kiwi can integrate into agricultural systems, particularly in areas where natural and modified habitats intersect. They have the potential to contribute to ecosystem services in pastoral and horticultural systems, including pest control. While their presence may help regulate insect populations that could otherwise impact crop and soil health, this relationship has not been thoroughly investigated before this study. It is unclear whether the current densities of kiwi are sufficient to have a meaningful impact on pest populations. Despite this, their potential role in promoting ecological balance and sustainability within these systems is worth exploring further. Integrating the brown kiwi into agricultural and horticultural systems offers opportunities for conservation efforts. Land managers and conservationists can develop strategies to support kiwi populations while encouraging sustainable land use practices. These efforts are essential for addressing the challenges posed by habitat loss and introduced predators while maintaining productive and resilient agricultural systems.

1.6 Study Sites

1.6.1 Kerikeri

Kerikeri is in the Northland region of New Zealand within the Bay of Islands, experiencing abundant rainfall and a mild climate with annual temperatures typically ranging between 12°C and 22°C (Conning & Miller, 1999). These climatic conditions favour the cultivation of diverse fruit crops, making Kerikeri one of New Zealand's most productive horticultural regions. The area is particularly renowned for its production of citrus fruits, kiwifruit, tamarillo, and avocado, which significantly contribute to the local horticultural economy. This productive agricultural landscape, combined with patches of native forests and regenerating bush, offers unique opportunities to explore the interaction between wildlife, such as the North Island brown kiwi, and horticultural land use.

Efforts to protect kiwi populations in Kerikeri include government-initiated pest control programs, supported by local community initiatives and private landowner participation. These programs involve regular trapping of invasive predators, such as stoats and possums, to enhance the survival of both kiwi chicks and adult birds. Such initiatives are essential for maintaining the ecological integrity of the region while bolstering kiwi populations (Northland Regional Council, n.d.). The Northland Regional Council emphasises the importance of integrated pest control efforts to protect biodiversity, including kiwi habitats, within the Kerikeri Ecological District.

Understanding how kiwi populations interact with this agricultural landscape is critical for crafting conservation strategies that ensure the long-term survival of kiwi populations while simultaneously supporting sustainable agricultural practices. These strategies are vital for addressing habitat loss and mitigating the impacts of introduced predators, ensuring that agricultural systems in the region remain productive and resilient.

This study was conducted at four sites in Kerikeri: The Landing Vineyard, Craigmore Orchard, Puriri Park Orchard, and Kainui Orchard (Figure 1.1). These sites were selected based on various factors, including reports of the North Island brown kiwi presence and existing collaborations with orchard owners (Department of Conservation [DOC], 1999; Northland Regional Council, n.d.). Moreover, each orchard has its own unique management practices and crop types, providing the opportunity to carefully select the horticultural environment best suited for this study.

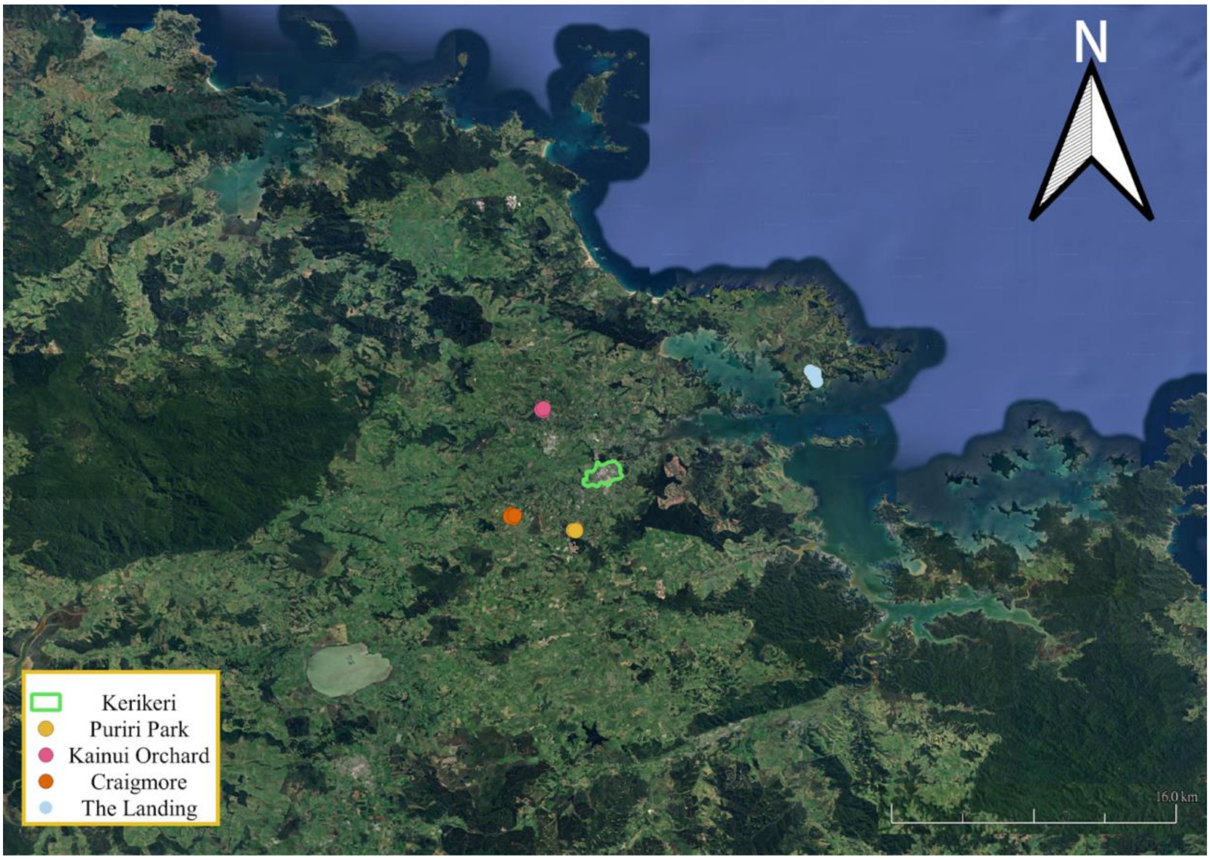


Fig. 1.1 Study sites- Kerikeri

1.6.2 The Landing

The Landing (Figure 1.2) (35°10’26” S, 174°04’49” E) is a luxury vineyard and estate with multiple residences. The vineyard is planted in clay and sandstone soils on slopes near the coastline. The area has 200 years of grape-growing history and is surrounded by farmland, native bush, and wetlands. Research has been conducted in this area since 2012, and it has been found that the North Island brown kiwi is present in this region. The vineyard covers 12 hectares and is bordered by a variety of habitats: wetlands, native bush, and urbanised areas where the North Island brown kiwi can be observed. For this project, 12 hectares were used.

1.6.3 Craigmore

Craigmore (Figure 1.2) (35°15’49” S, 173° 53' 53” E) is a former dairy farm now converted into a kiwifruit orchard with native plantings and a native forest fragment.

The landscape consists of undulating hills and flat areas, most of the property is dedicated to kiwifruit vines, approximately 70 of the total 130 hectares. The owners had reported hearing kiwi calls from the native forest and suspected that these birds venture into the orchard at night for foraging. Moreover, a preliminary study carried out by Plant and Food Research and Massey University captured the North Island brown kiwi calls using autonomous acoustic recorders. For this project, 12 of the 70 hectares were used.

1.6.4 Puriri Park

Puriri Park (Figure 1.2) (35° 15 '50.86” S, 173° 55' 55.50” E) is a 6-hectare kiwifruit orchard bordered by native bush. While the orchard itself does not contain any native bush within its boundaries, the surrounding native forest creates a close interface between the orchard and the bush. The orchard owners reported frequently hearing kiwi calls at night, suggesting that kiwi may venture into the orchard for foraging during the night due to its closeness to the native forest. For this project, the entire 6-hectare area of the orchard was utilised.

1.6.5 Kainui Orchard

Kainui Orchard (Figure 1.2) (35°11’25.21” S, 173°54’45” E) is a family-owned vineyard that has been growing grapes for the past 15 years on a 70-hectares property that also includes small areas for growing lemons, kiwifruit, avocados, and melons. The soil type is Kaihau friable gravelly clay, a very old weathered volcanic soil sitting over podzolic clay at varying depths. Despite its location, alongside a major highway, the surrounding area consists of interconnected native bush blocks, making it a potential foraging habitat for various forest species including kiwi. The vineyard has also implemented strict pest control for a long time. According to local media reports, the orchard was chosen based on information that kiwi calls were heard in the surrounding bush areas. It was therefore considered likely that this vineyard might serve as a suitable foraging area for kiwi. For this project, 8-hectares were used.

Fig. 1.2 Camera trap & Pitfall trap location in each study site. A. The Landing; B. Craigmore; C: Kainui; D. Puriri Park.

Yellow dots represent pitfall trap station locations used for invertebrate sampling. Blue dots indicate camera trap locations used for monitoring the North Island brown kiwi activity and the other species in the study sites.

1.7 Invertebrates in Vineyards and Kiwifruit Orchards

Invertebrates play a critical role in the ecosystems of vineyards and kiwifruit orchards. These organisms serve as both beneficial species and pests, influencing soil health, pest control, and overall ecological balance. Understanding the composition of invertebrate communities is essential for developing effective pest management strategies and promoting sustainable pastoral and horticultural practices (Table 1.2).

Vineyards are home to many invertebrate species that significantly contribute to soil health and pest control. Ground-dwelling species such as beetles (Coleoptera), spiders (Araneae), and springtails (Collembola) play essential roles in aerating soil, breaking down organic matter, and managing pest populations (Lavelle & Spain, 2001; Pollierer et al. 2015). For example, predatory beetles and spiders' prey on harmful insects like grapevine moths, aphids, and leafhoppers, which are common vineyard pests that can damage crops and reduce yields (Michalko et al. 2019; Thomson & Hoffmann, 2009). Similarly, in New Zealand, pitfall trap studies in vineyards from Northland recovered invertebrates such as beetles (Coleoptera), spiders (Araneae), grasshoppers (Orthoptera), and flies (Diptera), providing a clearer picture of invertebrate diversity and distribution in these ecosystems (Wijnands, 2020)

In a study conducted in Northern Italy, researchers found that vineyards using cover crops (plants that cover the soil but are not harvested) and reduced chemical inputs had higher invertebrate diversity, including a larger number of natural pest predators (Paoletti et al., 1995). These practices promote ecosystem resilience by enhancing biodiversity, which helps control pest populations.

Kiwifruit orchards, particularly in New Zealand, exhibit rich invertebrate communities that include both pests and beneficial organisms. Common pests in kiwifruit orchards include leafrollers (*Epiphyas postvittana*), scale insects (Diaspididae), and mealybugs (Pseudococcidae), which can cause significant damage to crops (Suckling & Brockerhoff, 2010). However, beneficial invertebrates, such as parasitic wasps (Braconidae & Encyrtidae), predatory beetles (Carabidae & Staphylinidae), and earthworms (Annelida), are essential for maintaining soil health and regulating pest populations (Edwards & Bohlen, 1996; Losey & Vaughan, 2006; Symondson et al.

2002). Research has shown that organic kiwifruit orchards typically support higher biodiversity compared to conventional or Integrated Pest Management (IPM) systems, particularly among predatory and parasitic species (Steven et al., 2007). IPM systems are a strategic approach to pest control that focuses on using a variety of sustainable methods to reduce the use of chemical pesticides. Its main goal is to prevent economic losses while protecting human health and the environment. The system integrates biological, mechanical and chemical control technologies and is applied through a careful monitoring and decision-making process. It emphasises the importance of understanding pest life cycles and interactions within the ecosystem to implement the most effective management strategies (Dara, 2019; Suckling et al., 2003). For example, biological control may involve the introduction of natural predators or parasites, while mechanical control may include traps or barriers. Under IPM, chemical methods are only used as a last resort when other strategies prove insufficient to address pest problems. IPM is widely recognised as an effective and environmentally friendly pest control method suitable for agriculture, forestry, and urban areas. This multi-faceted approach combines biological, cultural, and physical controls to manage pests, reducing the reliance on harmful pesticides that can contribute to pest resistance and environmental degradation when overused. By integrating natural pest control strategies, such as promoting beneficial invertebrates, IPM helps control pest populations naturally and minimises the long-term economic and ecological costs associated with traditional pesticide-heavy methods (Dhawan & Peshin, 2009). Additionally, these practices can create a more ecologically balanced orchard environment that not only supports sustainable pest management but also improves habitat conditions for the North Island brown kiwi.

Several methods are used to detect and collect invertebrates in vineyards and kiwifruit orchards (New, 1998). One of the most common techniques is the pitfall trap. It is a simple device buried at ground level that captures ground-dwelling invertebrates, including beetles, spiders, and ants as they move across the soil surface. Pitfall traps are widely used because they are cost-effective and easy to deploy (Luff, 1975; Spence & Niemelä, 1994). They also provide valuable data on species composition and abundance. In addition to traditional methods like pitfall traps, modern technologies, such as optoelectronic sensors and acoustic devices, are also employed to monitor soil-dwelling invertebrates. Optoelectronic sensors can detect invertebrate movement and activity in real-time, allowing for the continuous monitoring of pest populations (Balla et al. 2020). Acoustic devices, commonly used for detecting stored grain pests, can also be used to detect the presence of soil-dwelling species by picking up the sounds made as they move through the soil (Mankin et al., 2021). These advanced methods offer more detailed and continuous data, potentially helping vineyard and orchard managers better understand pest dynamics and take preventative measures (Albanese et al., 2021; Vanegas et al., 2018).

One of the primary purposes of this study was to determine the composition of invertebrate groups in vineyard and kiwifruit orchard's soils. This is a crucial first step in assessing whether native species, such as the brown kiwi, can contribute to controlling invertebrate pests. Understanding the diversity and abundance of invertebrate species in vineyards will enable managers to assess potential pest pressures and better implement pest management strategies. Moreover, this study sought to explore possible interactions between the brown kiwi and pest populations in vineyards. Given that kiwi is known to forage on invertebrates, understanding this relationship may open up new possibilities for integrating biological pest control methods into vineyard and orchard management. If the kiwi foraging behaviour can help regulate pest populations, this could provide a natural, sustainable solution to pest control. Investigating the potential role of the brown kiwi as a biological control agent may open up new opportunities for integrating conservation efforts with agricultural productivity.

1.7.1 Pests in New Zealand in Vineyards and Kiwifruit Orchards

In New Zealand's vineyards and kiwifruit orchards, a variety of pests, including mammals, birds, and invertebrates, pose significant threats to crop quality and yield. It is important to understand the different types of pests and their impact on maintaining agricultural productivity, including the most effective methods for controlling them. This section will focus on the pests in these environments, especially invertebrates because they are one of the main pests of vineyards and kiwifruit orchards and are in the diet of the North Island brown kiwi. Certain invertebrate species can cause severe damage to crop quality.

Common pests in horticultural settings include leafrollers (*Epiphyas postvittana*), mealybugs (Pseudococcidae), scale insects (Diaspididae), grapevine moths (*Phalaenoides glycinae*), and aphids (Aphidoidea) (Table 1.3). Leafrollers, mealybugs, and scale insects are particularly prevalent in kiwifruit orchards. Leafrollers primarily damage young leaves, flowers, and fruit, resulting in substantial economic losses (Steven et al., 2007). Sap-sucking pests, such as mealybugs and scale insects, weaken plants by inhibiting their growth, leading to further economic damage (Charles et al., 2014). Aphids are commonly found in vineyards and kiwifruit orchards, where they extract plant sap, weaken the plants, and slow their growth. Additionally, they spread plant viruses, which further compromise plant health and productivity. Moreover, they excrete a sugary substance called honeydew, which accumulates on the plant surface, attracting fungi that blacken leaves and fruit. This reduces photosynthesis and decreases the product's market value (Fereres & Moreno, 2009). Decreases in market value due to pest infestations are not unique to New Zealand and can be observed in other countries. For instance, pests such as the Mediterranean fruit fly cause significant crop damage and lead to export restrictions, resulting in an estimated over $2 billion annually in

Table 1.2 Invertebrate studies in vineyards and kiwifruit orchards

Study	Year	Method	Site	Habitat type	Acari	Araneae(Spider)
Wijnands	2020	Pitfall Trap	Northland region (The Landing,Omata state& Paroa Bay)	Vineyard		x (Opiliones)
Logan et al	2022	Pitfall Trap	Bay of Plenty (Te Puke)	Kiwifruit orchard + Adjacent native forests		
Briones et al	2014	Pitfall Trap	New Zealand	Kiwifruit orchard	x	
Todd et al	2016	Pitfall Trap	New Zealand	Kiwifruit orchard		x
Sullivan et al	2023	Pitfall Trap + Sweep Netting	Waipara,Motueka& Kerikeri	Vineyard + kiwifruit orchards + apple orchard		x (Araneidae,Lycosidae, Theridiidae, Linyphiidae, Desidae)
Booth et al	2003	Pitfall Trap	New Zealand	Vineyard		x
Lo et al	2018	Pitfall Trap	Hawke's Bay	Orchards and vineyards		
Todd et al	2011	Pitfall Trap	New Zealand	Kiwifruit orchard		x
Charles et al	2010	Visual inspections,yellow sticky traps, pitfall traps	Hawke's Bay, Gisborne,Marlborough, and Central Otago	Vineyard		
Lo et al	2009	Visual inspections, Sticky traps,	Hawke's Bay, Marlborough	Vineyard		

Study	Amphipoda	Annelida	Coleoptera	Mollusca	Centipedes+Diplopoda	Dermaptera	Diptera	Orthoptera	Hemiptera	Hymenoptera	Isopoda	Lepidoptera	Collembola	Trichoptera
Wijnands	x	x	x	x (Gastropoda)	x	x	x	x (Gryllidae)	x	x	x	x		x
Logan et al			x (Carabidae)											
Briones et al		x											x	
Todd et al		x	x										x	
Sullivan et al														
Booth et al		x	x											
Lo et al							x					x (Tortricidae)		
Todd et al			x										x	
Charles et al			x						x (Pseudococcidae, Aphidoidea, Diaspididae)	x				
Lo et al			x						x (Pseudococcidae, Diaspididae)					

losses for fruit producers (Sciarretta et al., 2018). Similarly, in India, insect pests such as those affecting wheat, barley, and pulses contribute to losses ranging from 10% to more than 25% of total production (Sharma et al., 2017). These examples highlight the global economic impact of pest infestations on agricultural productivity and market accessibility.

Some bird species can threaten vineyards and kiwifruit orchards by damaging fruit and reducing yield. For example, silvereyes peck at the fruit, particularly in vineyards, leading to losses (Tracey et al., 2007). This behaviour can have localised impacts on crop productivity, highlighting the challenges of managing bird activity in agricultural settings. Introduced bird species like blackbirds (*Turdus merula*), song thrush (*Turdus philomelos*), sparrows (*Passer domesticus*), and starlings (*Sturnus vulgaris*) are especially common in vineyards, where they feed on ripe grapes (Gray, 1991; Kross et al., 2012; Nelson, 1990). New Zealand's "Predator-Free 2050" initiative aims to eradicate invasive mammal predators, which in turn will contribute to the growth of native and non-native bird populations, potentially increasing the frequency of these interactions. Maintaining a balance between bird populations and agricultural and horticultural environments is essential for promoting ecological stability and sustainable crop production. Maintaining a balance involves managing bird populations to enhance their positive effects while reducing harmful effects. Bird species, both native and introduced, play critical roles in these ecosystems, acting as both pest controllers and potential crop predators (Porter, 1992). For example, the use of natural predators, such as New Zealand falcons, has been successful in reducing crop damage from invasive birds in vineyards. These predators help control problem birds by preying on them, thereby reducing the number of birds destroying crops (Kross et al. 2012). In addition, IPM strategies (including habitat modification and bird deterrent systems) are often used to help manage bird populations in horticultural environments (Witmer, 2007). These approaches aim to support the positive ecological roles of birds while minimising potential crop damage (Lindell et al., 2018). However, there is a notable lack of research on the efficacy of bird deterrents, many of which are non-specific and may indiscriminately impact a broad range of species. This highlights the importance of adopting ecologically sound management techniques that promote biodiversity while maintaining agricultural productivity (Lindell et al., 2018; Muñoz, 2017).

New Zealand's mammal pests, including possums, rabbits (*Oryctolagus cuniculus*), and rats, also reduce crop yields in vineyards and orchards (Nugent et al. 2001). Possums strip leaves and damage fruit, and rabbits and rats chew on young plants. Pest control methods in horticultural settings include chemical control, bird netting, trapping and poisoning, exclosure experiments, and other methods found effective in research (Collier et al., 2020; Malusá & Tartanus, 2020). In traditional orchards and vineyards, chemical treatments are still used to target specific invertebrate pests. However, the use of these chemicals is strictly regulated to reduce negative impacts on beneficial invertebrates and the surrounding environment. Organic orchards rely on biological controls more and avoid chemical pesticides. Mammal pests are typically controlled through trapping and poisoning. These strategies for mammal control are part of broader pest management plans designed to protect New Zealand’s native species (Germano et al., 2018). Additional pest control methods, such as exclosure experiments using nets or other barriers, exclude target pest species. This can help understand the impact of predators on invertebrate populations. New insights gained from these experiments can help improve biological pest control methods. Besides reducing economic losses, information from these experiments provides valuable information for conservation efforts. Effective pest management in New Zealand’s vineyards and kiwifruit orchards

Table 1.3 Pest Invertebrate studies in vineyards and kiwifruit orchards

Study	Year	Method	Site	Habitat type
Lo et al	2018	Pitfall Trap	Hawke’s Bay	Orchards and Vineyards
Todd et al	2018	Pitfall Trap	New Zealand	Kiwifruit orchard
Charles et al	2010	Visual inspections, Sticky traps, pitfall traps	Hawke's Bay, Gisborne,Marlborough, and Central Otago	Vineyard
Lo et al	2009	Visual inspections, Sticky traps,	Hawke's Bay, Marlborough	Vineyard
Charles	1982	Visual inspections, Sticky traps, pitfall traps	Auckland	Vineyard
Edwards et al	2008	Visual inspections, Sticky traps,	New Zealand (Bay of Plenty)	Kiwifruit orchard
Logan et al	2017	Visual inspections, Sticky traps,	New Zealand (Bay of Plenty)	Kiwifruit orchard
Loch	2005	Visual inspections, Sticky traps, pitfall traps	Australia and New Zealand	Vineyard

Study	Treatment	Tortricidae	Hemiptera	Dermaptera	Coleoptera	Lepidoptera
Lo et al	Unknown	x				
Todd et al	Unknown	x				
Charles et al	Biological control, insecticide		x (Pseudococcidae)			
Lo et al	Biological control, insecticide		x (Pseudococcidae)			
Charles	Insecticide		x (Pseudococcidae)			
Edwards et al	Biological control, insecticide		x (Diaspididae)			
Logan et al	Biological control		x (Diaspididae)	x (Forficulidae)	x (Coccinellidae)	
Loch	Biological control					x (Noctuidae)

requires a multifaceted approach. By combining various control strategies, it is possible to effectively control pest populations while protecting beneficial organisms and maintaining ecosystem health.

1.8 Thesis Research

1.8.1 Aims

- Gain the evidence of the North Island brown kiwi using horticulture areas to forage.
- Investigate the possible role of the North Island brown kiwi as a pest controller in two horticultural settings: kiwi fruit orchards and vineyards.
- Provide the orchardists with information on improving their horticultural practice for the North Island brown kiwi.

1.8.2 Goals

- Describe the North Island brown kiwi use of pastoral and horticultural areas using autonomous recording units and camera traps and describe kiwi foraging behaviours in vineyards and orchards using camera traps.
- Compare the North Island brown kiwi diet invertebrate composition with the common invertebrate pest species in vineyards and orchards. Determine whether pest invertebrate groups are common in the North Island brown kiwi's diet.
- Compare differences in environmental conditions for the North Island Brown Kiwi in each horticultural farm.

1.8.3 Importance of thesis

- By using the camera trap results, we can assess whether the North Island brown kiwi is adapting their behaviour in response to human-caused environmental changes in horticultural settings. Specifically, this includes examining whether their behaviour shifts in highly modified environments, such as vineyards and orchards, compared to their typical activities in more natural habitats.

- Potential pest control by the North Island brown kiwi could offer growers an efficient way to reduce costs associated with managing invertebrate pests while also serving as an appealing marketing strategy. Highlighting this potential may not significantly increase public awareness of kiwi conservation, as they are already an iconic species. However, it could incentivize more growers to encourage kiwi onto their properties, integrating conservation efforts with sustainable horticultural practices.
- This study aims to explore how kiwi foraging behaviour aligns with the environmental conditions in orchards, providing insights that could help orchard owners improve habitat suitability for the North Island brown kiwi. Enhancing these conditions would support the creation of "Kiwi Eco-Friendly Orchards," a concept that combines conservation efforts with sustainable land use practices. Such orchards could also serve as a unique marketing opportunity, appealing to environmentally conscious consumers (Coleman, 2010). By implementing habitat improvements based on research findings, growers may attract and sustain kiwi populations, integrating conservation with productive horticultural practice. This approach underscores the potential for dual benefits: supporting kiwi conservation while enhancing the orchard's ecological and economic value.

1.8.4 Thesis Structure

This thesis contains four chapters. In Chapter 2, I will present the results from a pitfall and faecal analysis study conducted at each orchard, focusing on the invertebrate species composition and the diet of the North Island brown kiwi. In Chapter 3, I will present findings on the active times and foraging activities of the North Island brown kiwi in each orchard and adjacent forest areas. In Chapter 4, I will provide an interpretation of the combined results from Chapters 2 and 3, supported by data from diet analysis, camera traps, and acoustic recorders. Additionally, this chapter will include information about other vertebrates using the orchards, offering a broader context for understanding the orchard ecosystems.

CHAPTER TWO

The Diet of North Island Brown Kiwi and Invertebrates Found in Orchards

Plate 3.1 – Male brown kiwi foraging in Craigmore orchard area. Photo by author.

2.1 Introduction

The North Island brown kiwi is a nocturnal, flightless bird native to New Zealand, known for its reliance on invertebrates as a primary food source (Bull, 1959; Gurr, 1952; Watt, 1971). Research on kiwi foraging ecology has traditionally focused on their feeding habits in forested environments (Colbourne & Powlesland, 1988; Reid et al., 1982), and their ability to exploit modified landscapes, such as orchards and vineyards, remains poorly understood. Given the increasing anthropogenic modifications to kiwi habitats, understanding their dietary adaptations in horticultural environments is critical for assessing their ecological role and conservation needs.

Studies analysing kiwi diet have frequently highlighted the significance of invertebrates, with Coleoptera (beetles), Orthoptera (grasshoppers), and other soil-dwelling invertebrates forming key components of their diet (Colbourne et al., 1990; Watt, 1971). Reid et al. (1982) conducted a large-scale analysis of gizzard contents from 50 North Island brown kiwi, confirming their preference for invertebrates associated with soil and leaf litter. More recently, Dixon (2016) emphasised the importance of moisture-rich soils in sustaining high invertebrate densities, which directly influence kiwi foraging success. This supports earlier observations by Kleinpaste and Colbourne (1983), who found that kiwi actively forage in microhabitats with high soil invertebrate availability, such as decomposing wood and organic-rich forest floors. Colbourne et al. (1990) further demonstrated that the abundance of invertebrates in kiwi foraging areas directly affects their feeding efficiency.

The shift from native forests to human-modified landscapes, such as orchards and vineyards, introduces new variables that may alter kiwi diet composition. While past studies suggest that forested environments are preferred habitats for kiwi, evidence from

Cunningham & Castro (2011) and Dixon (2015) indicates that kiwi are capable of foraging in pastures and modified landscapes if soil conditions remain suitable. However, little research has investigated the extent to which horticultural environments provide adequate invertebrate resources for kiwi. Orchards often support a mix of beneficial invertebrates and agricultural pests, presenting an opportunity to explore the kiwi's potential contribution to pest control (Dhawan & Peshin, 2009). Previous dietary studies, including those by Colbourne & Powlesland (1988), Shapiro (2005), and Reid et al. (1982), provide a foundation for assessing kiwi diet composition in modified environments. Additionally, Strang (2013) highlighted potential competition between kiwi and introduced mammalian species for invertebrate prey, raising further questions about resource availability in agricultural settings.

Faecal analysis is a widely used, non-invasive method for studying the diet of cryptic and endangered species (Deagle et al., 2007; MacLeod & Kerly, 1996). This approach has proven reliable for assessing insectivorous diets, as demonstrated by Dickman & Huang (1988) and further applied to kiwi by Shapiro (2005). By comparing invertebrates found in kiwi faeces with those captured in pitfall traps across different orchard sites, this study aims to determine dietary overlaps and identify key invertebrate taxa consumed by kiwi in modified landscapes. Earlier studies on kiwi diet through stomach content analysis (Bull, 1959; Gurr, 1952; Reid et al., 1982) provide useful comparative data for evaluating dietary changes in modified habitats.

The overarching goal of this chapter is to evaluate whether the North Island brown kiwi contributes to pest control within horticultural settings and how their dietary patterns vary across sites and seasons. The findings will provide valuable information for understanding the ecological interactions between kiwi and invertebrate communities in managed landscapes.

This research builds on existing literature and combines data from pitfall trap collections and faecal analysis to address these questions. By revisiting key references and integrating new data, this chapter aims to provide a comprehensive understanding of the North Island brown kiwi's potential ecological role in vineyards and orchards, offering insights that could inform both conservation strategies and sustainable horticultural practices. This chapter aims to address three key research questions:

What is the invertebrate composition in vineyards and orchards, and how does it vary across seasons?

Understanding the seasonal dynamics of invertebrate populations in modified habitats is crucial for assessing the availability of food resources for kiwi and their potential impact on these ecosystems.

What is the composition of invertebrates in the brown kiwi's diet?

Analysis of kiwi faeces can provide insights into their dietary preferences and the extent to which their foraging reflects the invertebrate communities present in these settings.

Are there pest invertebrates present in brown kiwi's diet?

Many agricultural pests, such as caterpillars, weevils, and beetles, are known to damage crops (Dhawan & Peshin, 2009). Investigating whether these pests are part of the kiwi's diet could reveal their potential role as natural pest controllers in horticultural systems.

2.2 Methods

2.2.1 Pitfall traps

The North Island brown kiwi is a nocturnal, ground-dwelling insectivore, so I focused on sampling ground invertebrates using pitfall traps. These traps, which are dug into the soil, capture invertebrates as they move across the ground and fall into the trap. The invertebrates are preserved in a solution, such as Propylene glycol, for later identification in the laboratory. This method was chosen for its cost-effectiveness, simplicity, and ability to collect samples continuously. Moreover, it can provide sufficient sample sizes for statistical analysis (Koivula et al., 2003). The technique has been used successfully in other studies of kiwi diets (Shapiro, 2005; Dixon, 2015).

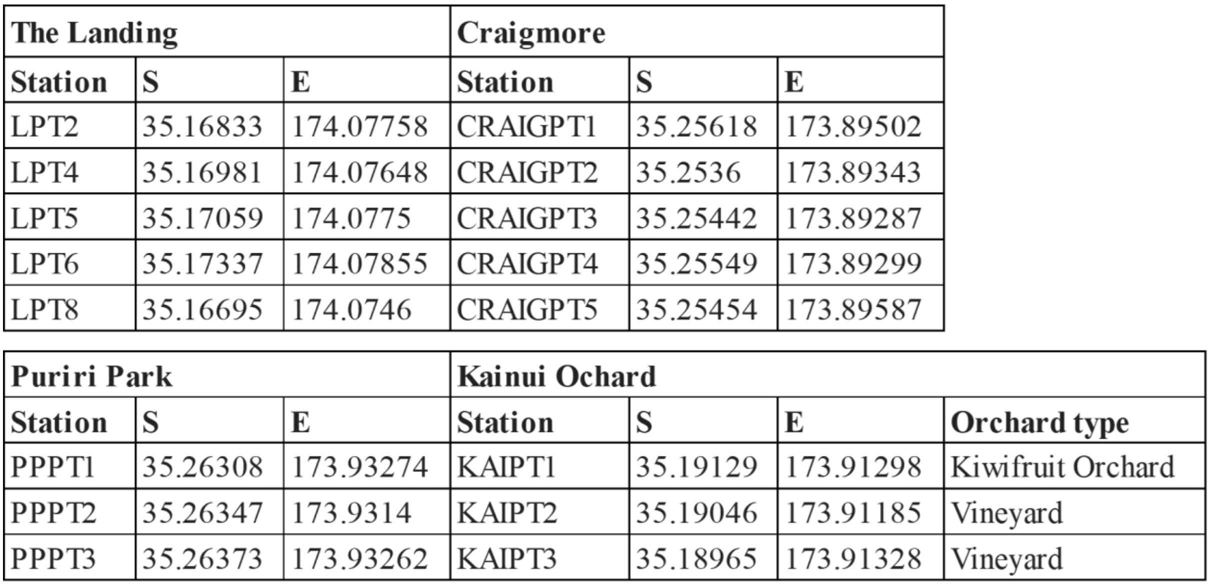
The equipment used for setting up the pitfall traps included plastic sleeves cut from 10-centimetre-long pipes and recyclable 266ml plastic cups. To install each trap, a hole was dug in the soil, and the hollow plastic sleeve was placed so that its top was flush with the ground. A plastic cup filled with approximately 4 cm of propylene glycol was inserted into the sleeve, ensuring that the cup's rim was level with the ground (Horne & Edward, 1997). The propylene glycol preserved the collected invertebrates, keeping them recognisable for identification and preventing them from escaping the trap. To protect the traps from external interference, metal covers were installed above them. These covers prevented debris from falling into the traps and safeguarded the collected invertebrates from potential predators. Designed to allow invertebrates to pass beneath without impacting trap efficiency, the covers also shielded the propylene glycol from dilution by rainwater, which could otherwise lead to inaccurate sampling. Additionally, to counteract the risk of the traps floating due to water accumulation in the outer sleeve during heavy rainfall, 4 oz sinkers were placed inside each plastic cup to maintain their stability. This setup ensured the traps remained effective in all weather conditions, maintaining the integrity of the invertebrate sampling process. The traps were deployed for approximately 14 days during each collection cycle, and the contents were emptied and processed directly at the trap stations in the orchards. These collection trips were spaced about one and a half months apart. Processing was conducted onsite to avoid relocating the traps and to preserve the integrity of the collected data. All collected invertebrates were then transported to the laboratory for further identification and classification.

The arrangement of pitfall traps was carefully planned to ensure proportional sampling across the study sites. For every 2-hectares of orchard area, one pitfall trap station was established. Each station consisted of five traps arranged systematically within the orchard to maximise coverage. The traps were positioned in a cross pattern, with one central trap and four additional traps placed equidistantly around it at approximately 3 meters apart. This layout was designed to capture a representative sample of ground-dwelling invertebrates while minimising potential biases related to trap placement. The larger study sites, The Landing and Craigmore, each had five trap stations to account for their greater areas. Puriri Park and Kainui Orchard, which were smaller, had three stations each. All trap stations were exclusively placed within the orchard areas to focus on the invertebrates interacting with these managed ecosystems. This standardised arrangement ensured consistent and representative sampling across all study sites, enabling robust comparisons of invertebrate communities in different environments.

Once the invertebrates were collected, the contents of each trap were labelled and transported to Massey University’s laboratory for further analysis. The samples were cleaned, and invertebrates with a total body length exceeding 1cm were identified. Identification was conducted primarily to the order level, using insect identification keys, though some groups were further classified to morphospecies or species level if necessary. For groups suspected of containing agricultural pests, efforts were made to identify them to the species level to assess their potential impact. If additional expertise was required for accurate classification, samples were sent to specialists. The identified invertebrates were then stored in a 70% ethanol solution for future reference and further analysis. This approach ensured that the data collected could inform both ecological studies and pest management strategies.

Each site represents a specific horticultural environment (Table 2.1). The Landing is characterised as a vineyard, while Craigmore and Puriri Park are kiwifruit orchards. Notably, Kainui Orchard differs from the other sites as it contains both a kiwifruit orchard and a vineyard, offering a mixed horticultural landscape. This distinction provides an opportunity to compare invertebrate dynamics across different crop types within the same site. The GPS coordinates for each station were recorded to ensure precise placement and enable reproducibility of sampling efforts. Stations within each site are labelled for clarity and consistency, ensuring comprehensive coverage of the respective horticultural zones. This table serves as a key reference for understanding the spatial organisation of the pitfall traps across varying horticultural settings.

Table 2.1. The GPS location (decimal degrees format) of pitfall trap stations at the four study sites included in this thesis. S = South; E = East.



The Landing			**Craigmore**		
Station	**S**	**E**	**Station**	**S**	**E**
LPT2	35.16833	174.07758	CRAIGPT1	35.25618	173.89502
LPT4	35.16981	174.07648	CRAIGPT2	35.2536	173.89343
LPT5	35.17059	174.0775	CRAIGPT3	35.25442	173.89287
LPT6	35.17337	174.07855	CRAIGPT4	35.25549	173.89299
LPT8	35.16695	174.0746	CRAIGPT5	35.25454	173.89587

Puriri Park			**Kainui Ochard**			
Station	**S**	**E**	**Station**	**S**	**E**	**Orchard type**
PPPT1	35.26308	173.93274	KAIPT1	35.19129	173.91298	Kiwifruit Orchard
PPPT2	35.26347	173.9314	KAIPT2	35.19046	173.91185	Vineyard
PPPT3	35.26373	173.93262	KAIPT3	35.18965	173.91328	Vineyard

2.2.2 Kiwi faeces

To study the North Island brown kiwi’s diet and its relationship with available invertebrates, I collected kiwi faeces and compared the invertebrates found in the faeces with those collected using pitfall traps. Kiwi faeces were identified based on their distinct smell (Colbourne et al., 1990), and the brown portion of the faeces was collected in sample bottles from the field. For uncertain samples, DNA analysis was outsourced to Plant & Food Research Ltd to confirm whether the faeces belonged to the North Island brown kiwi. The process involved extracting DNA from the faecal samples and amplifying specific regions of mitochondrial DNA using primers designed for kiwi species identification. The primers targeted conserved genetic sequences unique to the North Island brown kiwi, ensuring high specificity in the identification process. Faeces’s DNA were extracted using the method of Griffiths et al. (2000), where extracts were diluted 1:100 with water and amplified using Kapa Robust polymerase. The kcf2 and kcr2 primers from Shepherd et al. (2012) were used for amplification, as they have been previously validated for kiwi species identification. This additional verification step was crucial for eliminating any potential misidentification and ensuring the reliability of the faecal analysis results.

In the laboratory, I followed Dixon’s (2015) methods for identifying invertebrate prey remains in the faeces. In summary, faecal samples were defrosted and washed through a series of sieves with different mesh sizes (4000μm, 500μm, 250μm, 125μm). The largest sieve removed any vegetation, while the smallest sieve filtered out particles too small to analyse. The remaining material was transferred to Petri dishes for examination under an Olympus SZX7 Stereo microscope. Insect and plant material were separated manually, and all unfamiliar fragments were photographed for further identification and analysis. Fragments were identified to order level, and in the case of some beetles

(Coleoptera), to family level, by using an identification guide (Naumann et al., 1991). Invertebrates were conservatively counted based on their most recognisable body parts (e.g., beetle heads, cicada nymph forelegs, spider chelicerae). When multiple parts of the same type were present in one sample, the number of individuals was estimated using the largest complete count of a single part type. For example, if five beetle heads and eight beetle mandibles were found, the count was recorded as five individuals.

Finally, both the frequency of invertebrate occurrence and the number of individuals per sample were considered in the analysis to ensure robust and reliable results. This approach aligns with recommendations from prior studies emphasising the importance of combining frequency and abundance data to better understand dietary patterns in ecological studies (Dickman & Huang, 1988; Rosenberg & Cooper, 1990). Such methods enhance the ability to capture variability in invertebrate availability and dietary selectivity, which are crucial for interpreting ecological interactions accurately. Only the presence or absence of annelid chaetae was recorded, as Wroot (1985) noted that these structures are not reliable for estimating annelid numbers.

2.2.3 Data analyses

To analyse invertebrate communities and their relationship with kiwi presence across study sites, multiple analytical approaches were employed. The primary analyses included calculating capture rates from pitfall trap data, performing Non-metric Multidimensional Scaling (NMDS) to examine differences in invertebrate composition, and assessing the frequency of occurrence of invertebrate groups found in kiwi faeces.

Pitfall Trap Data and Capture Rate Calculation

Pitfall traps were deployed at each study site to assess invertebrate abundance and diversity. The capture rate (CR) for each site was calculated as:

$$CR = \frac{\text{Total number of individuals captured at a site}}{\text{Number of traps} \times \text{Sampling days}}$$

This standardisation allowed for direct comparisons of invertebrate abundance across different sites and seasons. The capture rates were then used to identify variations in invertebrate availability between vineyard and orchard environments, helping to determine whether habitat type influenced potential food resources for kiwi.

To explore differences in invertebrate community composition across study sites and seasons, Non-metric Multidimensional Scaling (NMDS) was performed. NMDS is a rank-based ordination technique that represents dissimilarity between samples in a reduced-dimensional space. The analysis was conducted using a Bray-Curtis dissimilarity matrix, which accounts for variations in both presence/absence and abundance of invertebrate groups.

- NMDS was used to visualise how invertebrate assemblages differed between study sites (e.g., vineyards vs. kiwifruit orchards) and across seasons.
- Stress values were examined to assess the goodness of fit of the ordination; values below 0.2 were considered acceptable.
- Site clustering patterns and potential correlations between environmental variables (e.g., soil type, canopy cover) were explored using vector fitting.

Frequency of Occurrence (FOO) of Invertebrate Groups in Kiwi Faeces

To assess kiwi diet composition and its potential role in pest management, invertebrate remains from kiwi faecal samples were analysed. The Frequency of Occurrence (FOO) for each invertebrate group was calculated as:

$$FOO(\%) = \left(\frac{\text{Number of samples containing a specific invertebrate group}}{\text{Total number of faecal samples analysed}}\right) \times 100$$

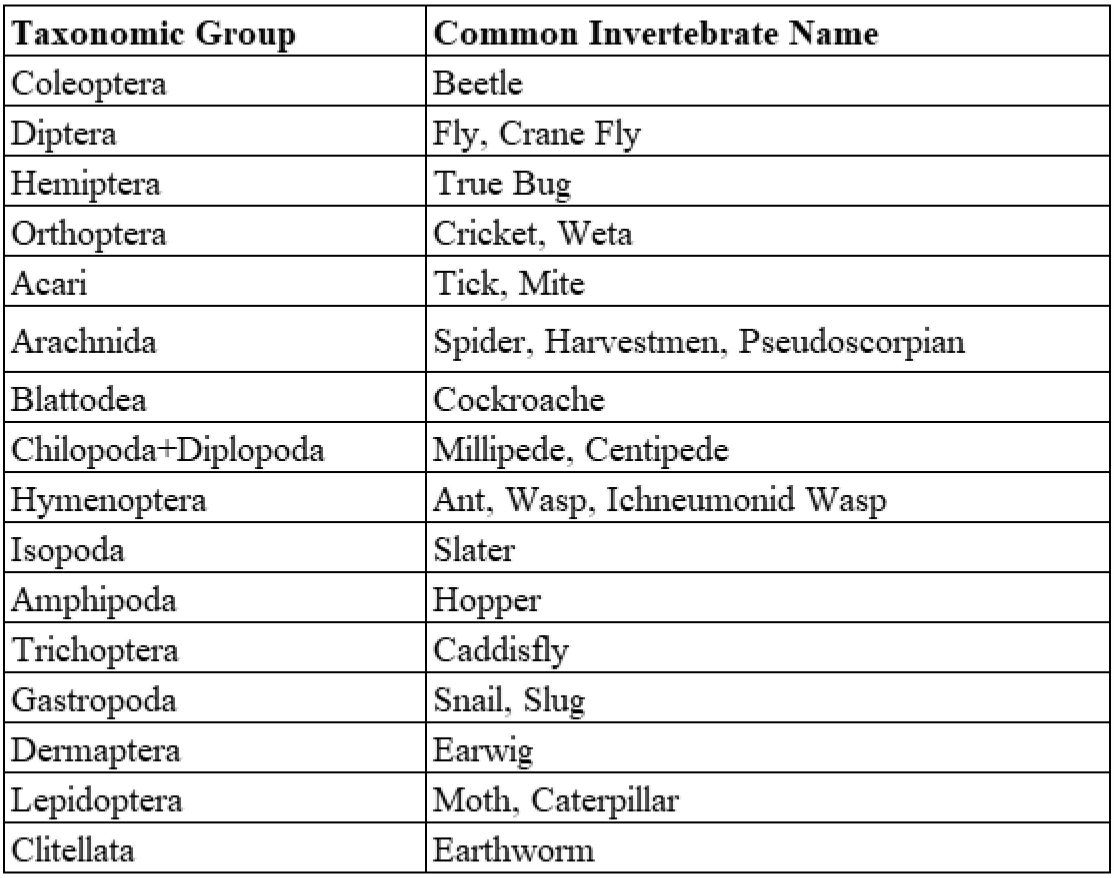
This metric provided insights into which invertebrate taxa were most frequently consumed by kiwi. By comparing faecal-derived invertebrate compositions with pitfall trap data, the study evaluated whether kiwi selectively foraged on specific invertebrate groups and whether their diet varied across sites and seasons.

2.3 Results

2.3.1 Pitfall traps

Table 2.2. provides a detailed classification of invertebrate groups identified during the study, serving as a reference for the subsequent results. It categorises the invertebrates into distinct taxonomic groups, including Coleoptera (beetles), Diptera (flies and crane flies), and Hemiptera (true bugs). Additional groups such as Orthoptera (crickets and weta), Acari (ticks and mites), and Arachnida (spiders, harvestmen, and pseudoscorpions) are also included. The table further specifies groups like Blattodea (cockroaches), Chilopoda + Diplopoda (millipedes and centipedes), Hymenoptera (ants, wasps, and ichneumonid wasps), and others such as Isopoda (slaters) and Amphipoda (hoppers). These classifications will guide the interpretation and organisation of the results, aligning the recorded data with the predefined taxonomic categories.

Table 2.2 Invertebrate Species Composition



Taxonomic Group	**Common Invertebrate Name**
Coleoptera	Beetle
Diptera	Fly, Crane Fly
Hemiptera	True Bug
Orthoptera	Cricket, Weta
Acari	Tick, Mite
Arachnida	Spider, Harvestmen, Pseudoscorpian
Blattodea	Cockroache
Chilopoda+Diplopoda	Millipede, Centipede
Hymenoptera	Ant, Wasp, Ichneumonid Wasp
Isopoda	Slater
Amphipoda	Hopper
Trichoptera	Caddisfly
Gastropoda	Snail, Slug
Dermaptera	Earwig
Lepidoptera	Moth, Caterpillar
Clitellata	Earthworm

Hymenoptera (mostly ants) recorded the highest capture rate, followed by Dermaptera and Clitellata. Tricladida showed lower capture rates (Figure 2.1). At The Landing (Figure 2.2), Hymenoptera showed the highest capture rate, significantly exceeding other invertebrate groups followed by Orthoptera. At Craigmore, Dermaptera dominated the captures, recording the highest rate, followed by Clitellata and Arachnida. In Puriri Park, Orthoptera also had the highest capture rate, followed by Coleoptera and Gastropoda. In Kainui Orchard, Orthoptera was again the most frequently captured group, with Amphipoda and Clitellata ranking second and third. These findings indicate that while Orthoptera was a dominant group in most sites, variations in the composition of secondary groups, such as Hymenoptera, Coleoptera, and Dermaptera, suggest potential habitat differences influencing invertebrate communities.

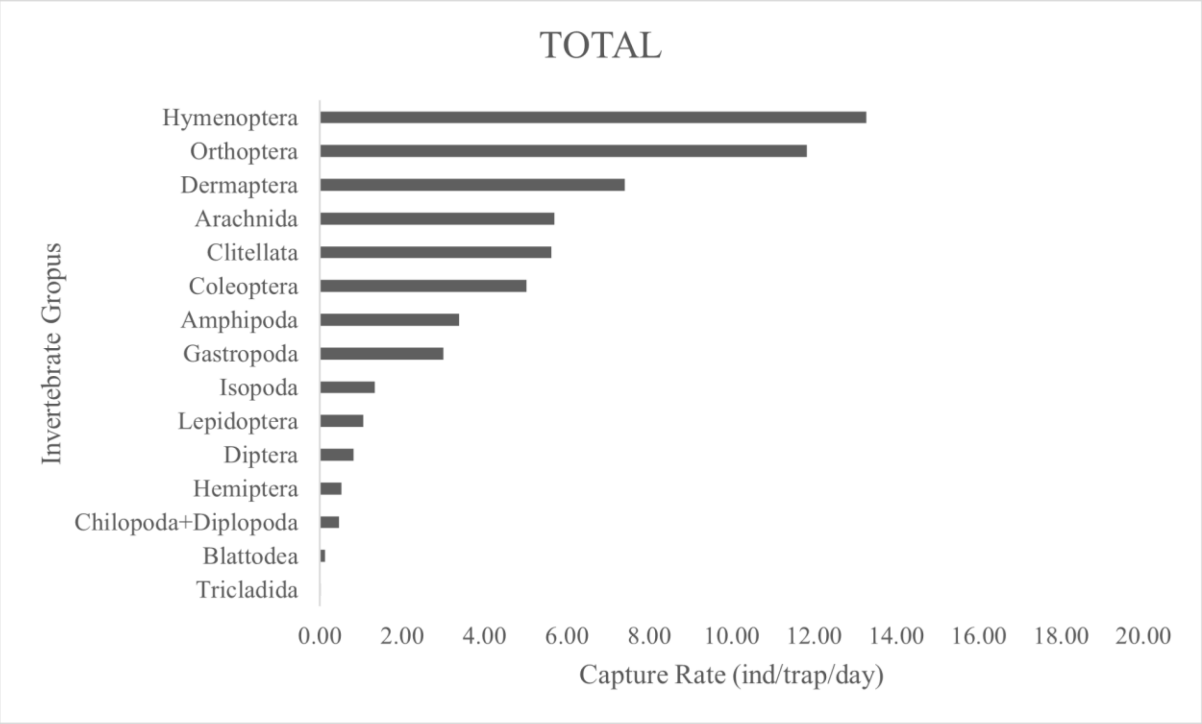


Figure 2.1 Pitfall trap Invertebrate Group Total Capture rate

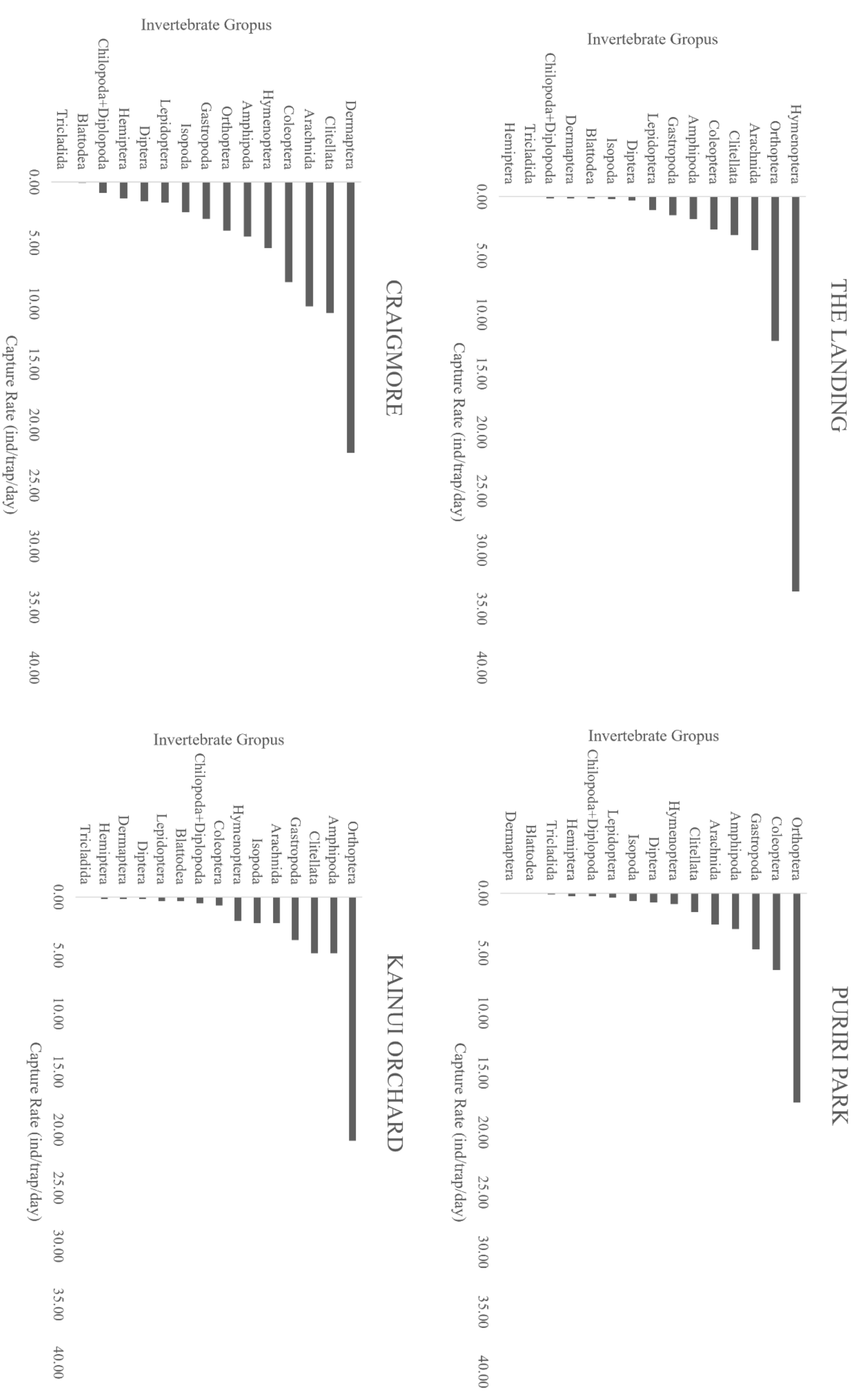


Figure 2.2. Pitfall trap Invertebrate Group Capture rate in each study site

2.3.1.1 Captures per location

Craigmore recorded the highest capture rate of invertebrates. The Landing had the second-highest capture rate, while Puriri Park had the lowest capture rate (Figure 2.3).

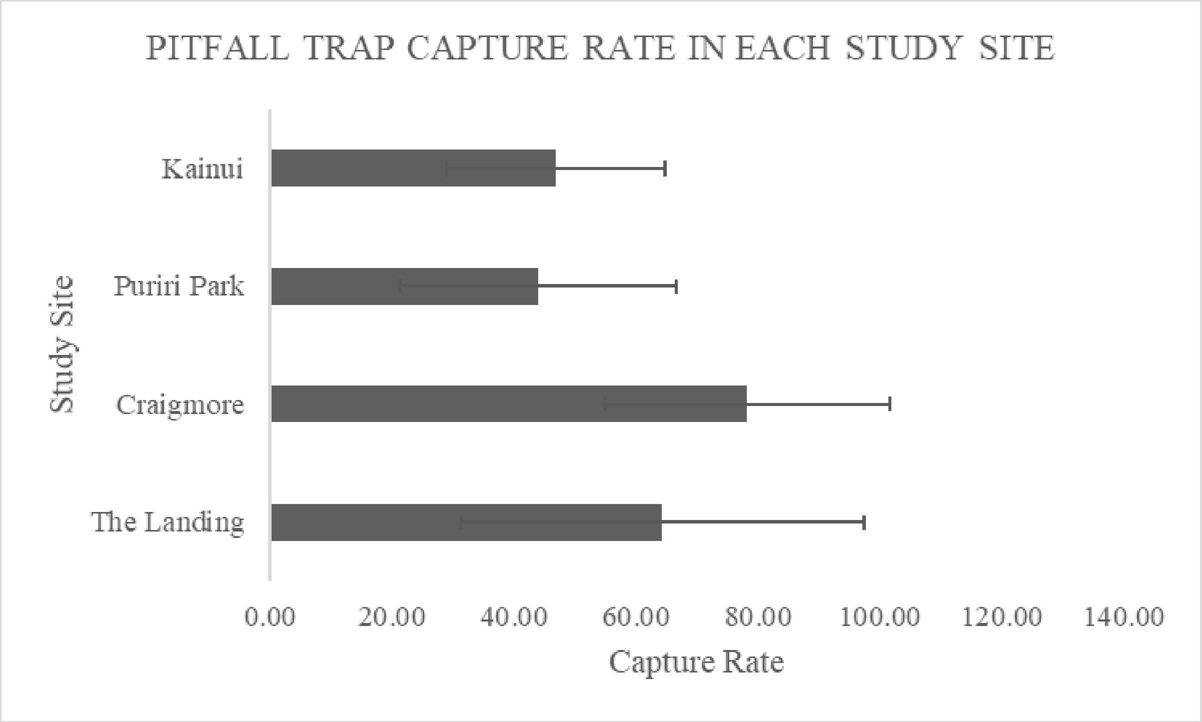
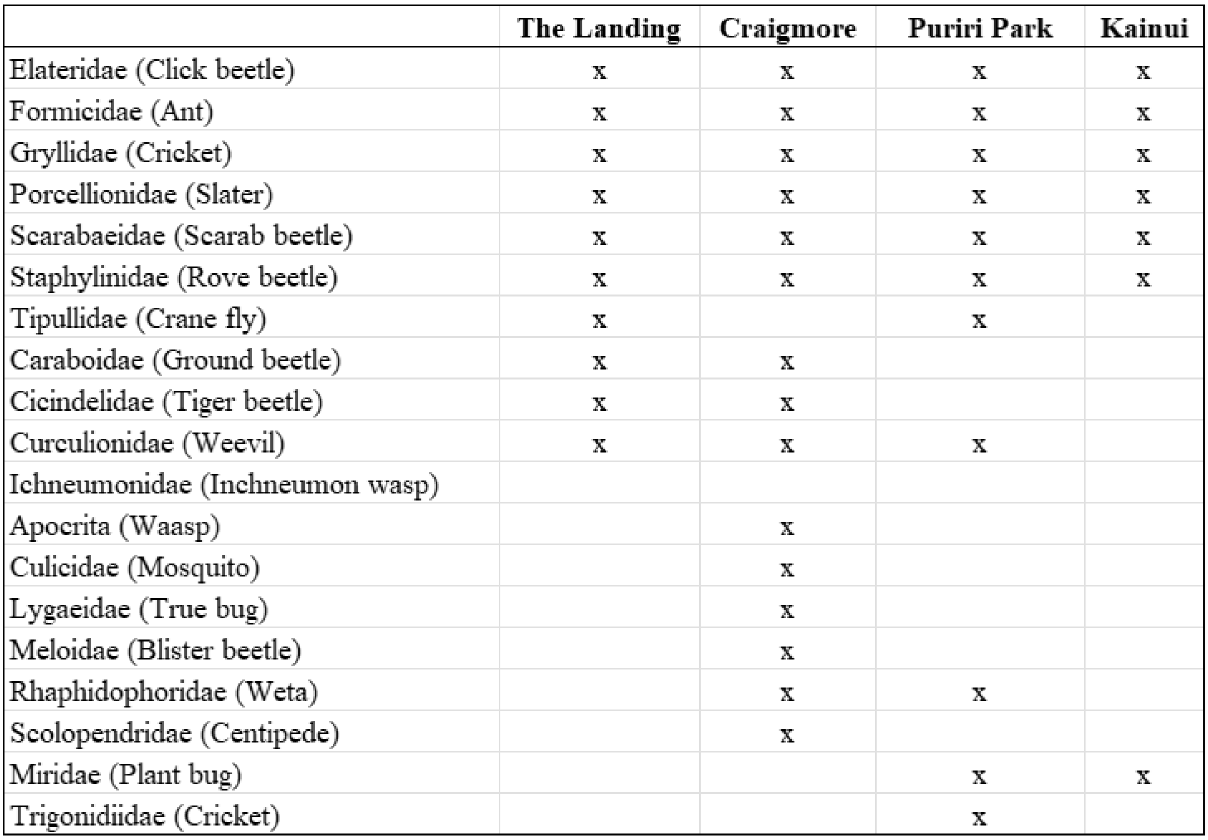


Figure 2.3 Results of Pitfall Invertebrate Capture Rate at Each Study Site.

Table 2.3 summarises the invertebrate species composition recorded in pitfall traps at the four study sites: The Landing, Craigmore, Puriri Park, and Kainui Orchard. Across all sites, certain families such as Elateridae, Formicidae, Gryllidae, Porcellionidae, and Scarabaeidae were consistently observed. Families like Staphylinidae and Tipulidae were also present in all locations, while other families such as Carabidae, Curculionidae, and Rhaphidophoridae were site-specific. Additionally, Ichneumonidae, Apocrita, and Trigonidiidae were observed in some sites but not all. Families like Culicidae, Lygaeidae, and Scolopendridae were recorded with lower representation across the sites. The data show variations in invertebrate family composition among the four locations.

Table 2.3. Pitfall trap invertebrate Species Family Composition in each study site



	The Landing	Craigmore	Puriri Park	Kainui
Elateridae (Click beetle)	x	x	x	x
Formicidae (Ant)	x	x	x	x
Gryllidae (Cricket)	x	x	x	x
Porcellionidae (Slater)	x	x	x	x
Scarabaeidae (Scarab beetle)	x	x	x	x
Staphylinidae (Rove beetle)	x	x	x	x
Tipullidae (Crane fly)	x		x	
Caraboidae (Ground beetle)	x	x		
Cicindelidae (Tiger beetle)	x	x		
Curculionidae (Weevil)	x	x	x	
Ichneumonidae (Inchneumon wasp)				
Apocrita (Waasp)		x		
Culicidae (Mosquito)		x		
Lygaeidae (True bug)		x		
Meloidae (Blister beetle)		x		
Rhaphidophoridae (Weta)		x	x	
Scolopendridae (Centipede)		x		
Miridae (Plant bug)			x	x
Trigonidiidae (Cricket)			x	

2.3.1.2 Captures per season

Figure 2.4 shows that in autumn, Craigmore recorded the highest capture rate, with the Landing showing a similar capture rate. Puriri Park recorded the lowest capture rate. In Winter, Craigmore again had the highest capture rate, and Puriri Park had the lowest. The second highest capture rate was recorded at Kainui Orchard, not at the Landing. Overall, the capture rates in Autumn were significantly higher than those recorded in Winter, indicating a seasonal variation in invertebrate activity.

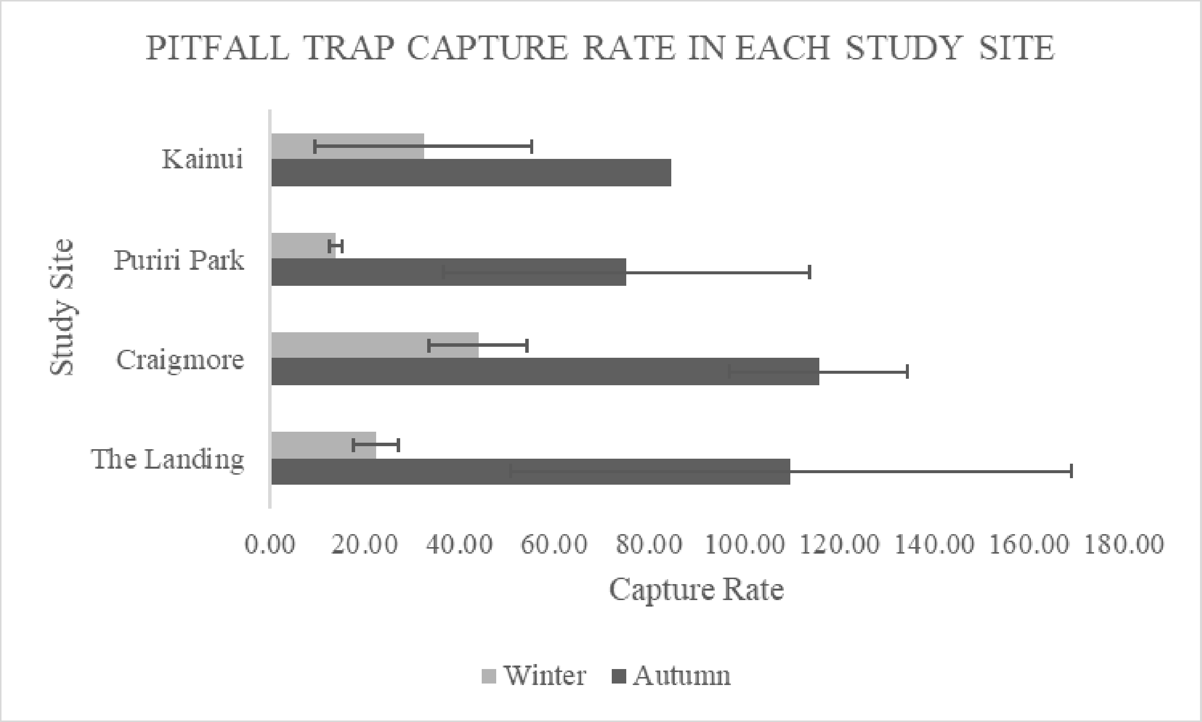


Figure 2.4 Pitfall trap capture rate in each study site between Autumn and Winter. Error bars are not shown for the Kainui orchard in autumn because only one data point was available for that location and season.

2.3.1.3 Comparison of Invertebrate Groups between the Study Sites

Non-metric Multidimensional Scaling (NMDS) analysis was performed to evaluate differences in invertebrate community composition across the study sites. The NMDS ordination plot (Figure 2.5) displays distinct clustering of invertebrate groups associated with each site, suggesting site-specific variations in community structure. The stress value for the NMDS analysis was 0.2019, indicating a reasonably good fit of the ordination model.

PERMANOVA results confirmed statistically significant differences in invertebrate composition between sites ($F = 2.4723$, $p = 0.001$), suggesting that site characteristics strongly influence invertebrate community structure. The proportion of variance explained by site differences was $R^2 = 0.20942$, indicating that approximately 21% of the variation in invertebrate composition can be attributed to site-specific factors.

Further analysis of centroids in the NMDS ordination revealed that invertebrate communities from Craigmore (C) and Puriri Park (P) were more distinct, whereas those from Kainui Orchard (K) and The Landing (L) showed moderate overlap. These findings indicate that habitat conditions at each site likely contribute to the observed differences in invertebrate assemblages.

The results suggest that environmental factors such as soil composition, vegetation cover, and resource availability may play a role in shaping invertebrate community structure. These findings provide a basis for further investigation into the ecological drivers influencing species composition across different horticultural and natural habitats.

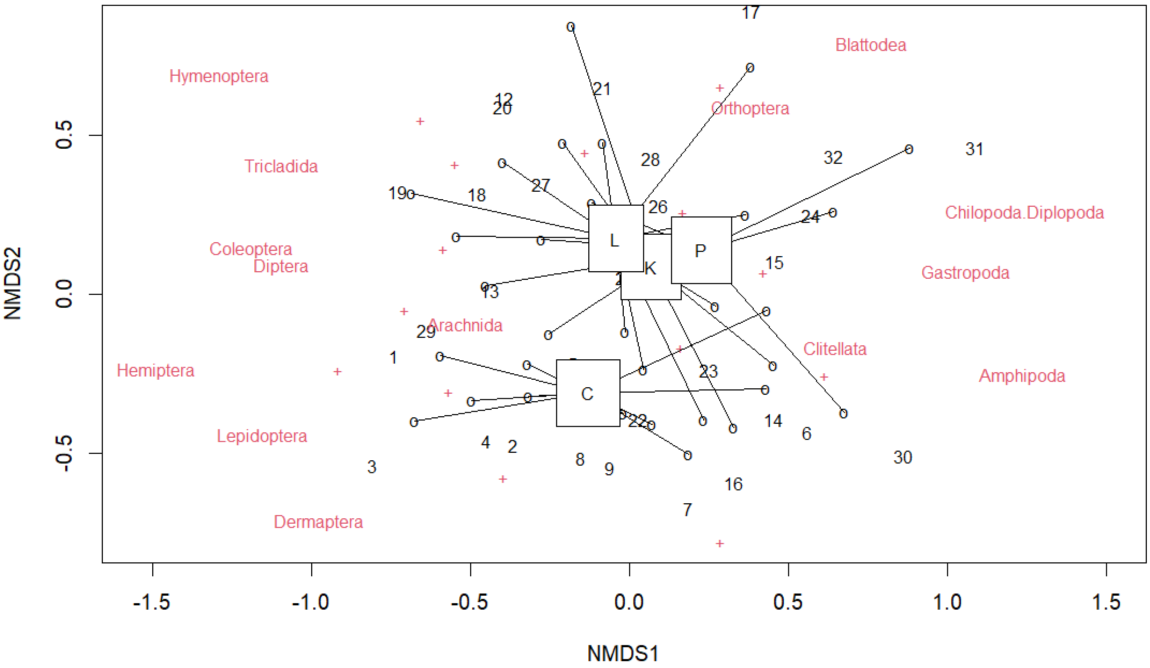


Figure 2.5 Non-metric Multidimensional Scaling (NMDS) Ordination Showing Differences in Invertebrate Groups Composition Across Study Sites. L = Landing; C=Craigmore; P = Puriri Park; K=Kainui Orchard

Non-metric multidimensional scaling (NMDS) analysis was performed to visualise differences in invertebrate community composition across seasons. The NMDS ordination plot (Figure 2.6) displayed a clear clustering of samples from different seasons, indicating distinct invertebrate assemblages in Autumn (A) and Winter (W).

The stress value for the NMDS ordination was 0.4249, suggesting a moderate fit between the ordination and the original data. A PERMANOVA test (adonis2) was conducted to assess statistical differences in invertebrate composition between seasons. The results revealed a significant effect of season on community composition ($F = 10.297$, $p = 0.001$, $R^2 = 0.2552$), indicating that 25.52% of the variation in invertebrate assemblages was explained by seasonal differences. These findings demonstrate a strong seasonal influence on invertebrate distribution, with clear compositional shifts between Autumn and Winter.

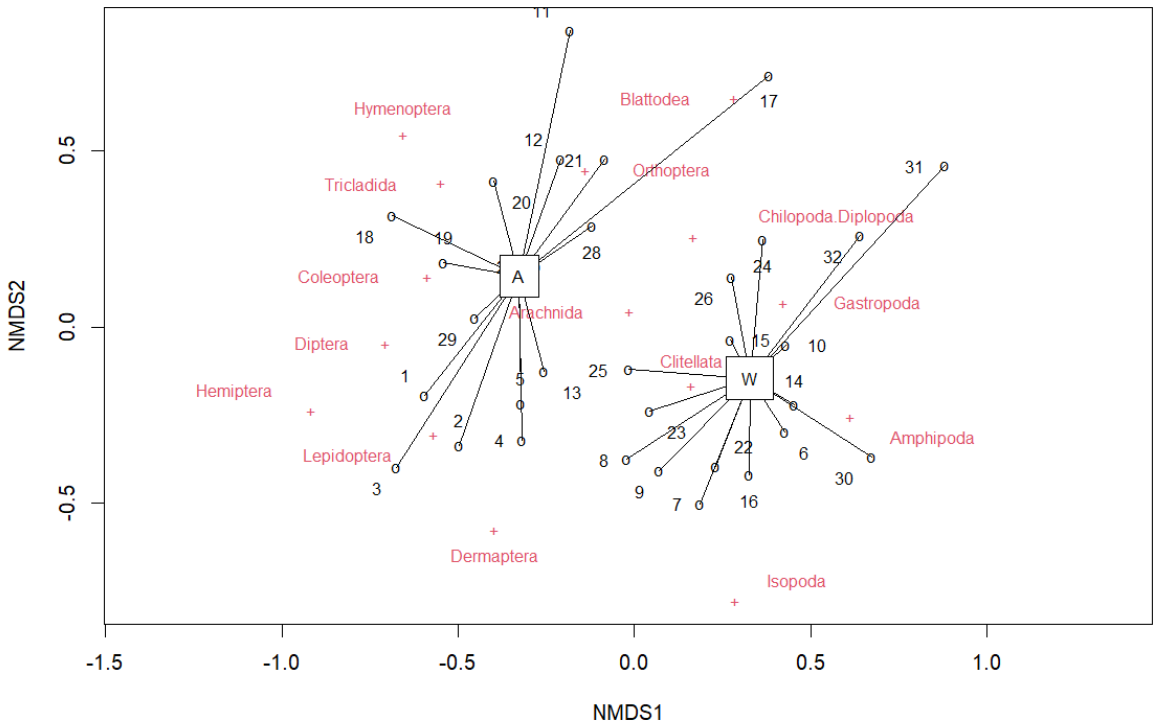


Figure 2.6. Non-metric Multidimensional Scaling (NMDS) Ordination Showing Seasonal Variation in Invertebrate Community Composition, A=Autumn; W=Winter

2.3.2 Kiwi Faeces

The pie chart (Figure 2.7) illustrates the invertebrate composition identified in kiwi faeces. The largest proportion consists of Coleoptera, which makes up 53% of the total composition. This is followed by Diptera, accounting for 15%, and Hymenoptera and Isopoda, each contributing 8% and 4%, respectively. Minor contributions include groups such as Gastropoda, Chilopoda+Diplopoda, and Blattodea, along with other taxa such as Hemiptera, Arachnida, and Orthoptera, each representing less than 4%. The chart also includes a category labelled ‘Unknown’ comprising a small portion of the composition. These percentages represent the relative abundance of each group within the faecal samples analysed.

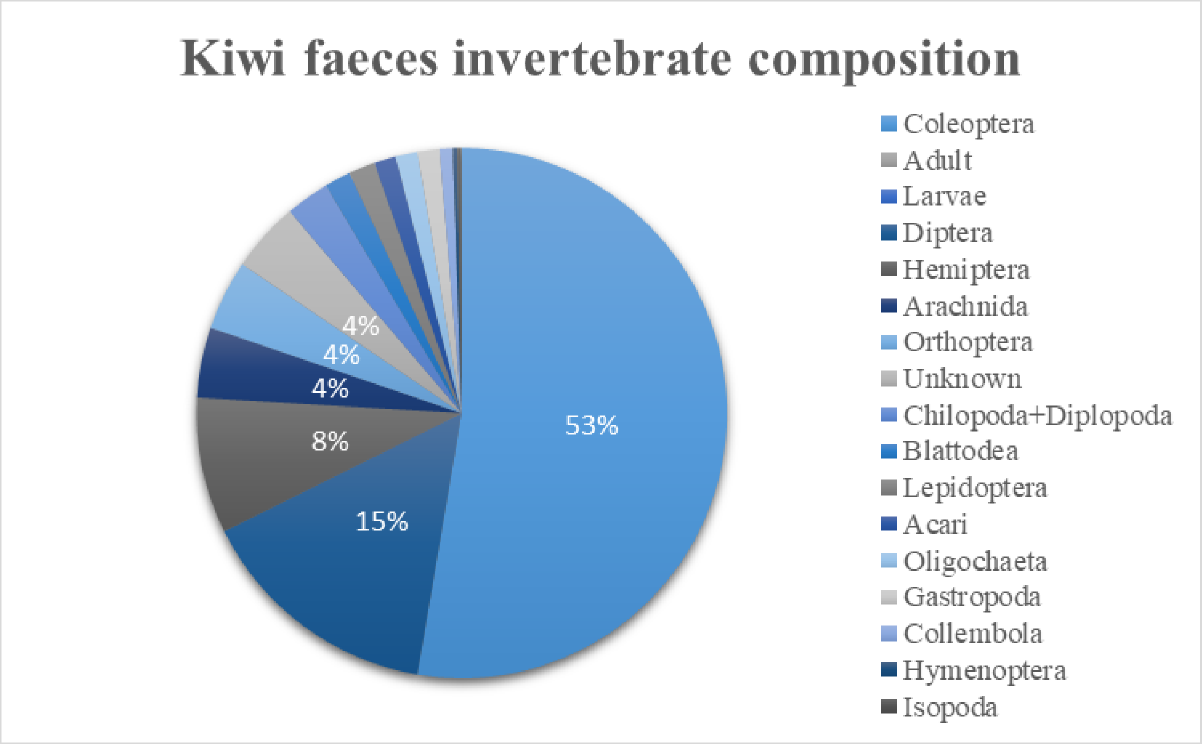


Figure 2.7. Relative abundance (percent) of each invertebrate group within kiwi faecal samples.

The line graph (Figure 2.8) depicts the monthly frequency of occurrence for various invertebrate groups across three months: March, June, and August. A significant peak is observed in June, where Coleoptera exhibits the highest frequency compared to all other groups. Most other invertebrate groups, such as Diptera, Hymenoptera, Chilopoda+Diplopoda, and Blattodea, maintain relatively low and stable frequencies throughout the months, with minor variations. In March and August, the frequencies of all invertebrate groups, including Orthoptera, Arachnida, and Gastropoda, are noticeably lower compared to June. This pattern highlights the temporal variation in invertebrate group frequencies over the observed period.

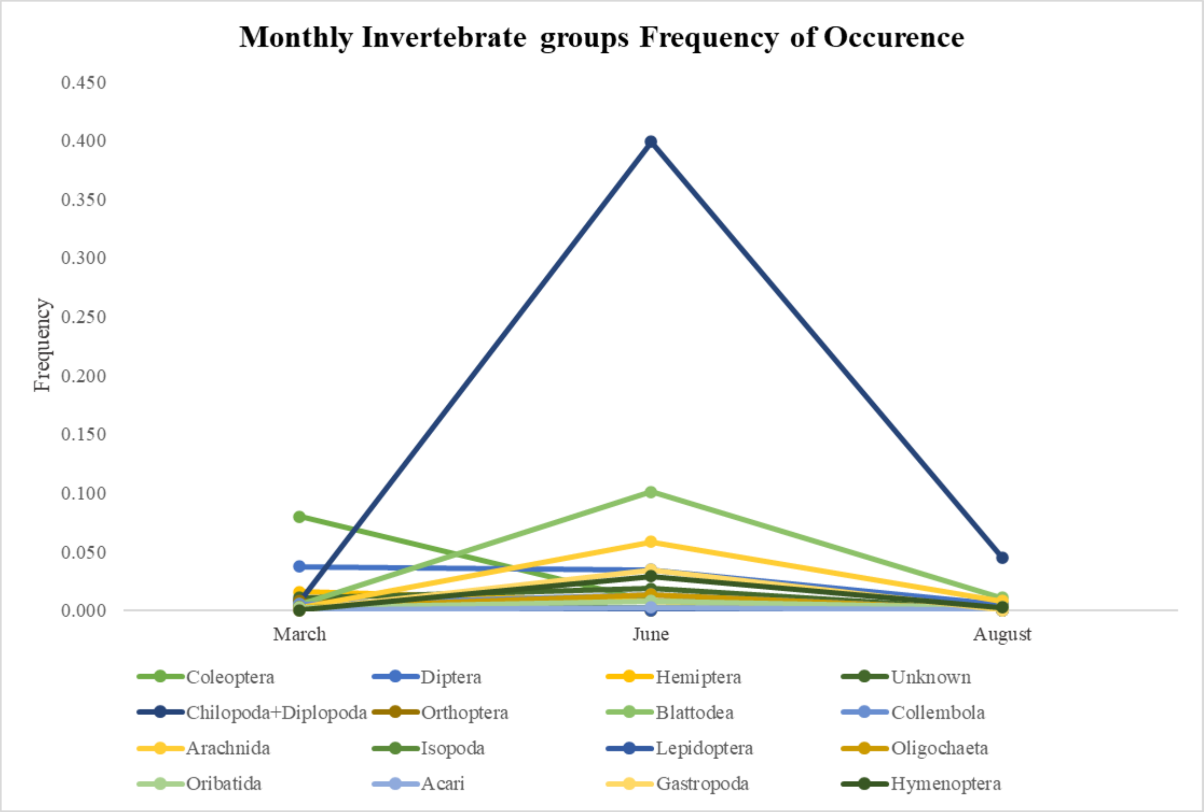


Figure 2.8 Monthly Invertebrate groups from kiwi faeces Frequency of Occurrence

2.3.3 Comparison of Invertebrate Composition: Pitfall Trap Collections, Kiwi Faeces, and Potential Pest Species

The invertebrate species composition across four horticultural environments (Table 2.4)—The Landing, Craigmore, Puriri Park, and Kainui Orchard—revealed notable findings. The analysis showed the presence of several common species across all locations. Caterpillars, scarab beetles, scarab beetle larvae, and snails were consistently found in both pitfall traps and kiwi faeces, as well as identified as common pests in these orchard environments. Crickets were also frequently recorded, with Crickets A (*Teleogryllus commodus*) appearing in both kiwi faeces and pitfall traps, while Crickets B (*Bobilla* sp., Māori: rirerire) were found only in pitfall traps. These findings demonstrate that several species have established themselves across different environments, adapting to varying conditions and playing roles both as pests and as part of the local ecosystem.

Darkling beetles, false blister beetles, and cicadas were found in kiwi faeces samples across multiple sites, with cicadas being present in both pitfall traps and faeces at Craigmore and Puriri Park. This suggests that these species are well-integrated into these particular environments. Species such as spiders and rove beetles were detected in both pitfall traps and faeces samples, highlighting their consistent presence across the different environments. The repeated detection of these species indicates their significant presence and importance in the ecosystem, suggesting that they play crucial roles in maintaining ecological balance.

At The Landing (Table 2.5), scarab beetles, caterpillars, crickets, and slugs were recorded as both orchard pests and in pitfall traps. This shows their adaptability and widespread distribution within the orchard setting. Spiders, rove beetles, and earthworms were also noted in kiwi faeces, indicating their presence within this particular habitat and their role as part of the diet of kiwi. The consistent presence of these species in faeces suggests that they contribute significantly to the diet of kiwi, and their availability in the environment may be an important factor for kiwi foraging behaviour.

In Craigmore (Table 2.6), scarab beetles, snails, and scarab beetle larvae were found in all sampling methods, indicating their prevalence in this environment. Hoppers and cicadas were predominantly recorded in kiwi faeces, suggesting they form a part of the kiwi diet in this area. Other species such as mites, ground beetles, and millipedes were also consistently found in faeces samples, demonstrating their presence in the habitat and potential role in the diet of kiwi. These findings underline the diverse composition of invertebrates in Craigmore, with certain species appearing consistently across different sampling methods.

Puriri Park (Table 2.7) had consistent findings of crickets, scarab beetles, and slugs in both pitfall traps and as common pests. This suggests these species are well-distributed and have established themselves within the environment. Species such as spiders, rove beetles, and earthworms were found in both pitfall traps and kiwi faeces, highlighting their availability in the environment and their importance as a food source for kiwi. Darkling beetles and cicadas were also detected in faeces samples from Puriri Park, indicating their role in the diet of kiwi in this specific environment. The presence of these species in multiple sampling methods points to their significance in the overall ecosystem of Puriri Park.

Kainui Orchard (Table 2.8) showed the presence of scarab beetles, snails, and spiders across multiple sampling methods, indicating these species are widespread within this environment. Cockroaches and earthworms were frequently observed in both pitfall traps and faeces samples, suggesting they are both common and accessible to kiwi as a food source. Centipedes, millipedes, and slugs were recorded as orchard pests, showing their potential impact on the horticultural environment. The repeated presence of these species across different sampling methods highlights their adaptability and role in the orchard ecosystem.

These results provide a detailed summary of the invertebrate species composition across different horticultural environments, highlighting the widespread occurrence of certain species and the unique distribution patterns observed at each site. The consistent presence of key species across multiple environments underscores their adaptability and ecological importance. Each environment displayed a unique composition of invertebrates, yet several species were common across all sites, reflecting their ability to thrive in diverse conditions. This comprehensive overview of species composition helps to understand the complexity and dynamics of invertebrate communities within these horticultural landscapes, emphasizing both the commonalities and unique features of each site.

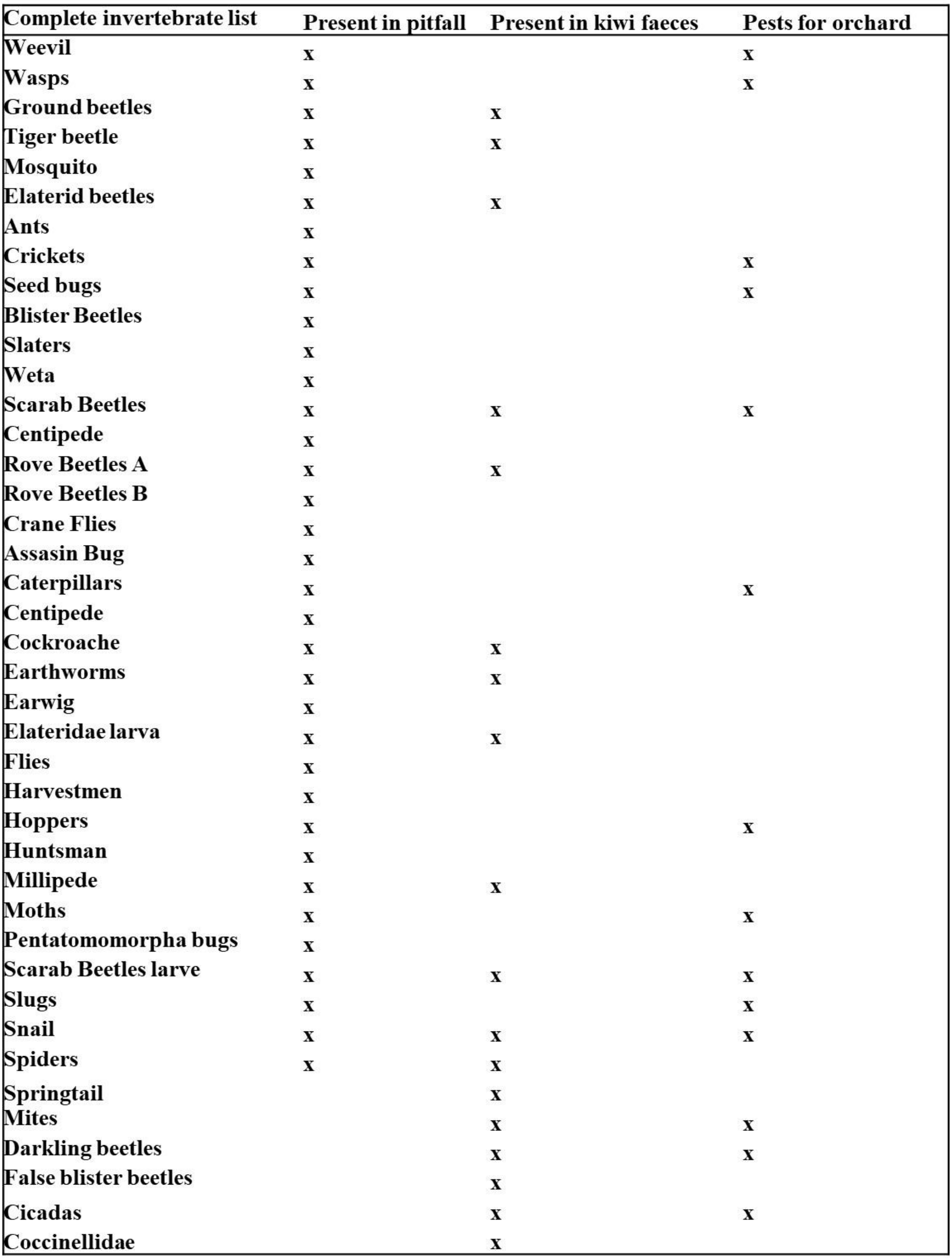
Table 2.4 Kiwi faeces, Pitfall trap, common pest invertebrate Species Composition. Crickets A = (*Teleogryllus commodus*). Crickets B = *Bobilla* sp., Māori: rirerire).

Invertebrates Groups	In Pitfall,Kiwi Faeces and Pest for orchard	In Pitfall and Pest for orchard	In Kiwi Faeces and Pest for orchard	In Pitfall and Kiwi Faeces
Caterpillars	x	x	x	x
Crickets A	x	x	x	x
Scarab Beetles	x	x	x	x
Scarab Beetles larve	x	x	x	x
Snail	x	x	x	x
Centipede				x
Cockroaches				x
Earthworms				x
Elaterid beetles				x
Elateridae larva				x
Ground beetles				x
Millipede				x
Rove Beetles A				x
Spiders				x
Tiger beetle				x
Mites			x	
Cicadas			x	
Crickets B		x		
Hoppers		x		
Moths		x		
Pentatomomorpha Bugs		x		
Seed bugs		x		
Slugs		x		
Weevil		x		
Darkling beetles		x		
False blister beetles		x		

Table 2.5 Kiwi faeces, Pitfall trap, common pest invertebrate Species Composition - the Landing

Complete invertebrate list	Present in pitfall	Present in kiwi faeces	Pests for orchard
Weevil	x		x
Crickets	x		x
Scarab Beetles	x	x	x
Caterpillars	x		x
Hoppers	x		x
Moths	x		x
Slugs	x		x
Mites		x	x
Darkling beetles		x	x
Cicadas		x	x
Ground beetles	x	x	
Tiger beetle	x	x	
Elaterid beetles	x	x	
Ants	x		
Ichneumonid Wasp	x		
Slaters	x		
Rove Beetles	x	x	
Crane Flies	x		
Centipede	x		
Cockroaches	x		
Earthworms	x	x	
Earwig	x		
Elateridae larva	x	x	
Flies	x		
Harvestmen	x		
Huntsman	x		
Millipede	x	x	
Spiders	x	x	
Springtail		x	
False blister beetles		x	
Coccinellidae		x	

Table 2.6 Kiwi faeces, Pitfall trap, common pest invertebrate Species Composition – Craigmore. Rove Beetles A = *Staphylinidae* (unresolved beyond family level; distinct from B). Rove Beetles B = *Staphylinidae*: Xantholinini.



Complete invertebrate list	Present in pitfall	Present in kiwi faeces	Pests for orchard
Weevil	x		x
Wasps	x		x
Ground beetles	x	x	
Tiger beetle	x	x	
Mosquito	x		
Elaterid beetles	x	x	
Ants	x		
Crickets	x		x
Seed bugs	x		x
Blister Beetles	x		
Slaters	x		
Weta	x		
Scarab Beetles	x	x	x
Centipede	x		
Rove Beetles A	x	x	
Rove Beetles B	x		
Crane Flies	x		
Assasin Bug	x		
Caterpillars	x		x
Centipede	x		
Cockroache	x	x	
Earthworms	x	x	
Earwig	x		
Elateridae larva	x	x	
Flies	x		
Harvestmen	x		
Hoppers	x		x
Huntsman	x		
Millipede	x	x	
Moths	x		x
Pentatomomorpha bugs	x		
Scarab Beetles larve	x	x	x
Slugs	x		x
Snail	x	x	x
Spiders	x	x	
Springtail		x	
Mites		x	x
Darkling beetles		x	x
False blister beetles		x	
Cicadas		x	x
Coccinellidae		x	

Table 2.7 Kiwi faeces, Pitfall trap, common pest invertebrate Species Composition - Puriri Park. Crickets A = (*Teleogryllus commodus*). Crickets B = *Bobilla* sp., Māori: rirerire). Rove Beetles A = *Staphylinidae* (unresolved beyond family level; distinct from B). Rove Beetles B = *Staphylinidae*: Xantholinini.

Complete invertebrate list	Present in pitfall	Present in kiwi faeces	Pests for orchard
Crickets A	x		x
Slugs	x		x
Hoppers	x		x
Spiders	x	x	
Scarab Beetles	x	x	x
Rove Beetles A	x	x	
Earthworms	x	x	
Snail	x	x	x
Elaterid beetles	x	x	
Ants	x		
Weevil	x		x
Slaters	x		
Weta	x		
Flies	x		
Crickets B	x		
Plant Bugs	x		
Crane Flies	x		
Pentatomomorph Bug	x		
Planarian	x		
Scarab Beetles larve	x		x
Millipede	x	x	
Rove Beetles B	x		
Caterpillars	x		x
Springtail		x	
Mites		x	x
Darkling beetles		x	x
False blister beetles		x	
Cicadas		x	x
Coccinellidae		x	

Table 2.8 Kiwi faeces, Pitfall trap, common pest invertebrate Species Composition - Kainui orchard

Complete invertebrate list	Present in pitfall	Present in kiwi faeces	Pests for orchard
Elaterid beetles	x	x	
Ants	x		
Crickets	x		x
Plant Bugs	x		
Slaters	x		
Scarab Beetles	x	x	x
Rove Beetles	x	x	
Caterpillars	x		x
Centipede	x		
Cockroaches	x	x	
Earthworms	x	x	
Earwig	x		
Flies	x		
Harvestmen	x		
Hoppers	x		x
Millipede	x	x	
Slugs	x		x
Snail	x	x	x
Spiders	x	x	
Springtail		x	
Mites		x	x
Darkling beetles		x	x
False blister beetles		x	
Cicadas		x	x
Coccinellidae		x	

Coleoptera represented the largest group, making up the highest proportion of an invertebrate type found in faeces and pitfall samples. Orthoptera followed as the second most common group, with smaller proportions attributed to Lepidoptera and Gastropoda. These results highlight the relative abundance of different pest invertebrate groups present in the samples.

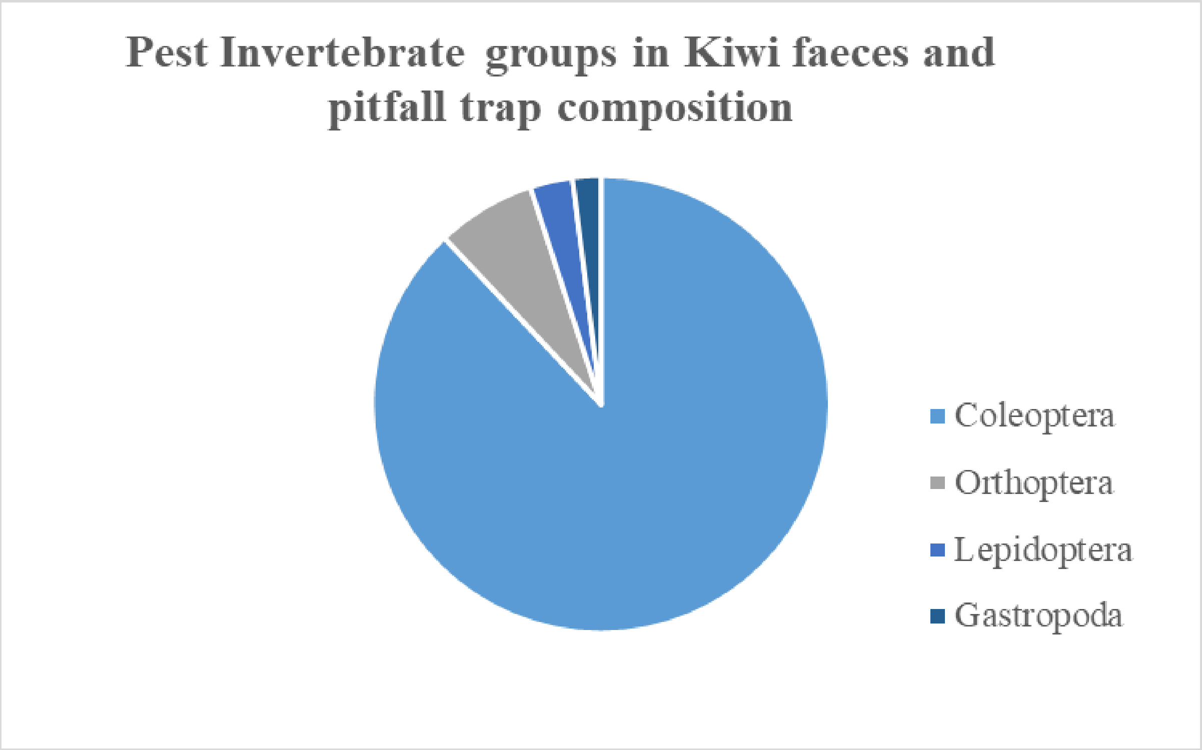


Figure 2.9 Proportion of pest invertebrate groups identified in kiwi faeces and pitfall trap samples

2.4 Discussion

2.4.1 Pitfall traps

The pitfall trap and kiwi faeces results in this study provide key insights into the diversity and distribution of invertebrate communities across the four study sites. By examining the differences between sites and seasons, this research offers a valuable perspective on the habitat factors that shape invertebrate populations and, indirectly, how they may provide ecosystem services. The findings also open the door for a deeper understanding of the North Island brown kiwi's potential contributions to pest control and ecosystem balance in horticultural landscapes. However, given the limitations of the data, these remain speculative.

2.4.1.1 Captures per location & per season

The study revealed notable seasonal variations in invertebrate capture rates, with significantly higher captures in Autumn compared to Winter across all sites. This disparity is likely due to increased invertebrate activity during the warmer months when conditions are more favourable for reproduction, movement, and foraging. Warmer temperatures and abundant food resources during Autumn may have allowed invertebrate populations to thrive, leading to higher activity levels and following capture rates (Junker & Cross, 2014). In contrast, Winter's cooler temperatures and reduced vegetation growth may have driven invertebrates to burrow into soil or deeper vegetation layers, resulting in lower surface activity and reduced trap effectiveness. These findings align with established research on seasonal invertebrate dynamics in temperate ecosystems, where colder periods are often associated with lower activity levels (Surdo et al., 2024). Site-specific differences further highlight the influence of habitat features on invertebrate community composition and capture rates. Craigmore consistently recorded the highest capture rates among all sites. Its open environment with minimal canopy cover and drier soil conditions might have facilitated greater movement of ground-dwelling invertebrates, making them more likely to fall into pitfall traps (Siewers et al., 2014; Litavský & Prokop, 2023). The relatively dry soil and lack of dense vegetation could have also encouraged certain taxa, such as ants (Hymenoptera), to dominate the landscape, as these species thrive in open and arid conditions (Miguelena & Baker, 2019; Menke et al., 2011). However, while Craigmore exhibited high capture rates, it is important to recognise that these results may not directly correlate with overall biodiversity or ecosystem health. Open environments may favour specific groups of invertebrates while excluding others, leading to an uneven representation of species diversity.

In contrast, The Landing demonstrated high capture rates for Hymenoptera, particularly ants, which was influenced by its moist soil conditions and close to temporary water bodies. The wetter environment likely created favourable conditions for ants to forage and establish colonies (Tschinkel & King, 2017). Additionally, the nesting behaviour of ants on the underside of pitfall trap covers likely inflated their capture rates. Ants building nests under the metal covers often fell into the traps, highlighting their adaptability and resourcefulness in utilising microhabitats. While this phenomenon provides insight into ant behaviour, it also introduces potential biases in interpreting their abundance and dominance from pitfall trap data.

Puriri Park, characterised by its extensive shrub cover, shaded environment, and consistently damp soil conditions, recorded the lowest capture rates. Shaded and moist microhabitats may favour species that are less active on the ground or those that primarily inhabit canopy layers, making them less likely to be captured by pitfall traps. This underscores the limitations of pitfall trapping in habitats with dense vegetation and high moisture levels, where other sampling methods may be more effective in capturing a broader range of invertebrates.

Kainui Orchard, with its moderate vegetation and typical orchard management practices, exhibited intermediate capture rates. The balanced habitat conditions at this site likely supported a diverse range of invertebrates, with Hymenoptera and Dermaptera dominating the captures. These taxa are commonly associated with agricultural landscapes and may play important roles in pest control and nutrient cycling (Arnold, 2022; Gupta, 2020).

Hymenoptera dominated the capture rates across all sites, emphasising their numerical dominance in these ecosystems. Ants, as a major subgroup of Hymenoptera, are known to play critical roles in ecological processes, particularly as predators of other invertebrates (Capinera, 2008). Their potential contributions to pest control in vineyards and orchards warrant further investigation. Ants are highly adaptable and capable of exerting significant predation pressure on pest populations, which could provide natural pest control benefits. While their abundance in pitfall traps suggests they are an integral part of the invertebrate community, additional studies are needed to quantify their functional contributions to pest regulation.

Coleoptera, another significant group captured in the traps, are widely recognised for their ecological roles in nutrient cycling, soil aeration, and decomposition (Verma et al., 2023). In particular, beetles contribute to the breakdown of organic matter and the maintenance of soil health. Their high capture rates in Craigmore and The Landing suggest that these sites may benefit from the ecological functions provided by Coleoptera. However, it is important to note that not all beetle species are beneficial. Some Coleoptera species, such as leaf beetles and root borers, are agricultural pests that can damage crops and reduce yields (Kariyanna, 2017; Patole, 2017). This dual role highlights the need for species-specific investigations to better understand the contributions of Coleoptera to ecosystem services in agricultural landscapes.

The presence of other taxa, such as Dermaptera (earwigs) and Isopoda (slaters), also provides insights into the functional diversity of invertebrate communities at these sites. Dermaptera are known for their omnivorous diet, which includes pest species such as aphids and small caterpillars (Flint, 2018). Similarly, Isopoda contributes to nutrient cycling through the decomposition of organic matter, particularly in moist environments (Yang & Li, 2020) like The Landing and Puriri Park. The functional roles of these groups underscore the complexity of invertebrate communities and their potential contributions to ecosystem services.

The overlap between trap catches and the diet composition of the North Island brown kiwi provides insights into ecological interactions in changing landscapes. Coleopterans are a major component of kiwi's diet, and their presence in large numbers at the study site suggests that kiwi actively feed on them. However, the impacts of kiwi predation on invertebrate communities remain uncertain due to the lack of precise estimates of kiwi consumption rates and invertebrate biomass. Although kiwi densities are relatively low in these environments, their impact on overall invertebrate abundance is unclear. Future studies should quantify the invertebrate uptake of kiwi and compare it with available biomass.

Despite these uncertainties, kiwi foraging may affect local ecological processes. Their digging and probing activities can affect soil structure and nutrient cycling, while predation on some invertebrates, including agricultural pests, may contribute to pest regulation in specific microhabitats. Further research is needed to determine the extent of these effects and whether kiwi foraging in orchards and vineyards has a measurable impact on invertebrate populations.

The results highlight the complex interplay between habitat features, invertebrate communities, and ecosystem services in agricultural landscapes. While the dominance of Hymenoptera and Coleoptera suggests potential functional contributions to pest control and soil health, these roles remain speculative in the absence of further evidence. Seasonal and site-specific variations highlight the importance of habitat management in supporting biodiversity and ecosystem function. As an insectivorous species, the North Island brown kiwi may play an active role in shaping invertebrate communities through predation. Its foraging behaviour includes probing and digging, which can affect soil aeration and nutrient cycling, while contributing to local pest control by consuming agricultural pest species. However, the extent of these ecological impacts remains uncertain. Interactions between kiwi and invertebrate communities in modified landscapes such as orchards and vineyards are poorly understood and require further investigation.

Future research should quantify the contributions of key invertebrate groups to ecosystem services and assess how kiwi predation affects invertebrate communities in these environments. Understanding these relationships will provide valuable insights into whether kiwi feeding benefits ecosystem processes such as pest regulation and soil health maintenance. By integrating ecological research with conservation and agricultural practices, it is possible to enhance biodiversity and the sustainability of horticultural systems while supporting kiwi populations in human-modified habitats.

2.4.1.2 Comparison of Invertebrate Groups between the Study Sites

Differences in invertebrate composition between study sites suggest that environmental conditions play a key role in shaping invertebrate communities. NMDS and PERMANOVA analyses showed significant differences among sites, with distinct groupings of invertebrate taxa. These findings highlight the influence of habitat characteristics, microclimate, and resource availability on the structure of invertebrate communities in different horticultural landscapes.

One of the most striking differences was the association of Arachnida and Diptera at Craigmore, which may be related to the lower canopy cover and drier soil conditions at the site. Arachnids, especially spiders, are well adapted to open environments where they can effectively hunt prey, whereas dipterans, including flies, often live in disturbed habitats. In contrast, The Landing and Puriri Park were more strongly associated with Chilopoda, Diplopoda, and Gastropoda. These taxa are often found in moist, organic-rich environments, suggesting that these sites may offer more stable moisture and soil conditions that are favourable to decomposers and scavengers.

Interestingly, the Kainui Ochard did not show strong aggregation with any particular invertebrate group but rather displayed a more mixed composition. This may indicate that habitat structure at Kainui supports a wider range of invertebrate species, or that environmental conditions fluctuate more frequently, preventing the dominance of particular taxa. Land management practices such as irrigation, pesticide use, and crop selection may also affect the invertebrate community at the site.

Seasonal variation is another important factor affecting invertebrate composition. NMDS ordination showed that Diptera and Coleoptera were more abundant in autumn, whereas Gastropoda, Chilopoda, and Diplopoda were more prominent in winter. This pattern shows that changes in temperature, humidity, and food availability can affect the distribution of invertebrates throughout the year. Higher humidity in the winter may create favourable conditions for decomposers, while fall temperatures may favour blooms of flying insects.

These findings suggest that environmental factors unique to each site play an important role in shaping invertebrate communities. Differences in soil conditions, vegetation cover, and microclimate may account for differences in invertebrate abundance and distribution. Further research should explore how these habitat characteristics interact with kiwi foraging behaviour to better understand the ecological dynamics of modified landscapes. Studying the long-term effects of land-use practices on invertebrate communities and kiwifruit supply is critical for developing conservation and management strategies in these environments.

2.4.2 Kiwi Faeces

The composition of invertebrates found in kiwi faeces provides valuable insights into the dietary preference of the North Island brown kiwi in modified landscapes. Coleopterans accounted for the largest proportion of 53% of the total faeces' composition, indicating that beetles are their main food component. This is consistent with previous research (Dixon, 2015) showing kiwi selectively seek out invertebrates that are abundant in their environment. The high occurrence of Diptera (15%) further suggests that soft-bodied insects also have a great influence on their diet structure. However, it is unclear whether these represent deliberate dietary preferences or are simply consumed because they are available. The presence of Hymenoptera (8%) and Isopoda (4%) in faecal samples indicated that kiwi feeds on a variety of invertebrates. While the order Hymenoptera includes species that can serve as prey, their defence mechanisms, such as the venomous stings of some taxa, raise questions about whether kiwi selectively target certain members of this group or prey on them opportunistically. Isopods are well known for their role in the decomposition of organic matter, and kiwi may ingest isopods as they explore the soil, further supporting the idea that kiwi foraging behaviour is closely related to soil composition and structure.

Interestingly, smaller invertebrate groups such as Gastropods, Chilopoda+Dipoda, Blattodea, and Hemiptera were less represented, each contributing less than 4% of the total diet. These groups were often associated with soil and leaf litter habitats, reinforcing the hypothesis that kiwi forage primarily in microhabitats rich in organic matter. The presence of gastropods and diplopods suggests that kiwi may also be fed by scavengers, which could affect nutrient cycling in these ecosystems.

Seasonal variations in diet composition were evident, with coleopteran abundance peaking significantly in June. This pattern suggests that seasonal changes in invertebrate communities may influence kiwi dietary intake. As shown in the line graphs, the presence of all invertebrate groups was significantly lower in March and August, indicating that kiwi may adjust their foraging strategies based on prey availability. This raises an important question: how do seasonal fluctuations in invertebrate abundance affect kiwi feeding efficiency, particularly in modified environments where resource availability may differ from native forests? Another important consideration is the unknown class in stool analysis, which accounts for only a small fraction of the dataset. While these most likely represent unrecognisable degraded invertebrate remains, further molecular or DNA-based analyses could allow for more precise identification of these dietary components.

These findings suggest that kiwi may exhibit dietary plasticity, adjusting their foraging behaviour according to prey availability in different seasons. However, their degree of dependence on specific invertebrate groups remains uncertain. Future research should focus on analysing kiwi foraging preferences in more detail and consider factors such as prey nutritional value, availability, and potential impacts on invertebrate communities. Understanding these interactions is critical to assessing the ecological role of kiwi in modified landscapes and its potential contribution to pest regulation.

2.4.3 Kiwi Faeces, Pitfall Traps, and Potential Pest Invertebrates’ Species Composition

A comparison of invertebrates collected from traps and those found in kiwi faeces provided insight into the foraging habits of the North Island brown kiwi in orchard environments. Results showed significant overlap between the two datasets, with several taxa occurring in both sampling methods. This suggests that kiwi actively consume invertebrates commonly found in their environment.

Coleoptera, especially scarab beetles and their larvae, were the most common group found in traps and kiwi faeces. This is consistent with previous studies that have highlighted beetles as a major food component of kiwi (Reid et al., 1982; Charlotte, 2013). Their abundance in both sampling methods suggests that they are not only widespread in orchard habitats but also a preferred or readily available food source for kiwi. The dominance of Coleoptera in faecal samples further supports the hypothesis that kiwi selectively seek out beetles when encountered in sufficient numbers.

Orthoptera, including crickets and grasshoppers, are also recorded in both datasets. The presence of multiple species of crickets in the faecal samples suggests that kiwi actively prey on these insects when they are available. However, some species of crickets were only found in the traps, suggesting that kiwi may not prey equally on all available Orthoptera species. This variation may be due to differences in species behaviour, size, or habitat preferences that affect their detectability or accessibility as prey.

Gastropods (including snails) were another common taxon observed in both sampling methods. The persistent presence of snails in faecal samples suggests that kiwi incorporate snails into their diet, despite differences in snail mobility and detectability compared to more active prey such as beetles and crickets. Given that snails are often associated with moist environments, their consumption may also reflect kiwi foraging in specific microhabitats within the orchard environment.

In contrast, some invertebrate groups were recorded more frequently in traps than in faecal samples. This includes taxa such as Diptera (flies) and Lepidoptera (moths and caterpillars). Although these groups were present in the orchard environment, their low levels in faecal samples may indicate that they are not a major dietary component of kiwi. Factors such as prey mobility, nutritional value or foraging efficiency could explain why certain invertebrates are rare in the diet composition of kiwi despite their presence in the habitat. The overlap between trap collections and faecal samples highlights the ecological role of kiwi as opportunistic foragers that feed primarily on readily available invertebrates. However, the differences between the datasets suggest that kiwi may exhibit some degree of prey selection, perhaps influenced by seasonal availability, prey behaviour, or habitat structure. Further research is needed to determine the extent to which kiwi actively selects for specific invertebrates or whether their diet composition largely reflects the abundance of invertebrates in the orchard landscape.

Overall, these findings contribute to a broader understanding of the foraging ecology of kiwi in modified environments. By examining the relationship between available invertebrates and those consumed by kiwi, this study provides valuable insights into the adaptive nature of kiwi feeding behaviour in orchard ecosystems. Understanding these interactions is critical to assessing the potential role of kiwi in pest management and its overall ecological impact in these horticultural landscapes.

The findings in this chapter provide important insights into the relationships between invertebrate communities, the North Island brown kiwi foraging behaviour, and ecosystem dynamics within horticultural landscapes. By comparing trap collections with kiwi faeces, the study highlighted significant overlap in invertebrate composition, particularly between Coleoptera and Orthoptera, reinforcing the idea that kiwis actively consume the most abundant prey in their environment. The results suggest that kiwi exhibit dietary adaptations in response to seasonal changes in invertebrate availability. Agricultural pest species such as beetles, crickets, and snails were present in both faeces and trap samples, suggesting that kiwi may play a role in pest regulation, particularly in orchard ecosystems where these species are common.

Despite these promising observations, this study was limited by a relatively small sample size and a limited number of study sites. While the data suggest that kiwi may contribute to pest control in modified landscapes, further research is needed to quantify the extent of this impact. Future studies should consider increasing the number of study sites and incorporating larger sample sizes to better assess the relationship between kiwi density and its effects on invertebrate communities. Furthermore, monitoring kiwi populations over long periods of time and under different agricultural settings will provide a more complete understanding of their ecological roles. It is evident from the results of this chapter that kiwi has the potential to act as a natural pest controller, particularly in orchard environments where they may help regulate invertebrate populations. However, to fully assess their effectiveness in this role, future research should incorporate multi-site studies with larger sample sizes and include an assessment of kiwi population density. This will help determine whether the presence of kiwi significantly affects pest dynamics and whether conservation efforts can exploit their foraging behaviour as part of an integrated pest management strategy in New Zealand agricultural landscapes.

CHAPTER THREE

North Island Brown Kiwi Behaviour and Habitat Use in Orchards

Plate 4.1 – Two juvenile brown kiwi chasing each other in Puriri Park orchard area. Photo by author.

3.1 Introduction

As human agricultural landscapes expand, habitats of the North Island brown kiwi increasingly overlap with modified horticultural environments such as orchards and vineyards (Cunningham& Castro, 2011). Understanding how these environments influence kiwi behaviour, particularly foraging habits, is critical to determining whether these habitats offer benefits or present new challenges for kiwi conservation. This is particularly important because, in these environments, kiwi may come into contact with introduced mammalian predators, such as domestic cats and dogs, which are prevalent in agricultural areas (McLennan et al., 1996; Pierce et al., 1997; Robertson et al., 2011). Investigating the extent to which this occurs is crucial for assessing the role agriculture may play in kiwi conservation efforts.

The kiwi is a nocturnal bird that feeds primarily on invertebrates and is known for displaying highly adaptive foraging behaviour in a variety of habitats (Martin et al., 2007). Research has shown that, in native forest environments, kiwi use their beaks to probe the soil, combining touch and smell to locate invertebrates (Dixon, 2015). However, less is known about how they adapt their behaviour in modified landscapes, such as orchards, which may offer different resource availability and challenges compared to traditional forest habitats. Furthermore, while the presence of introduced predators in these environments is well documented, the extent to which predator activity overlaps with kiwi activity remains unclear. The decline of kiwi populations has been strongly linked to predation, with species such as stoats (*Mustela erminea*), feral cats (*Felis catus*), and dogs (*Canis lupus familiaris*) posing significant threats to both juvenile and adult kiwis (McLennan et al., 1996). Examining predator distribution in orchard environments will provide further insight into potential risks faced by kiwi in these modified landscapes.

Previous studies have explored kiwi behaviour in fragmented and modified landscapes. For example, research has examined the foraging patterns of kiwi in pasture and plantation habitats, providing insights into their adaptability and habitat use (Dixon, 2015; Taborsky & Taborsky, 1995; Wilson, 2014). These studies highlight the importance of understanding the interactions between kiwi and modified environments for developing effective conservation strategies. While kiwi have shown the ability to use non-native habitats, the suitability of orchards as foraging grounds remains uncertain. Differences in soil composition, prey availability, and vegetation structure may influence their habitat use and movement patterns.

This chapter investigates the behaviour and habitat use of the North Island Brown Kiwi in orchard environments. By examining their foraging habits, movement patterns, and predator exposure, we can better understand the impact of agricultural expansion on kiwi conservation. This knowledge is essential for developing effective management strategies that support both kiwi populations and sustainable land use.

To achieve this, camera traps and audio recorders were used to capture key behavioural patterns, providing insights into how kiwi adapt their foraging strategies in orchards compared to native bush environments. Specifically, I aim to answer two key questions:

- **Do brown kiwi use orchards for foraging, and how does their foraging behaviour in these environments compare with their behaviour in adjacent bush habitats?**

- **Is there a correlation between the activity of kiwi predators and the kiwi themselves, particularly in terms of predator numbers and the overlap in nocturnal activity?**

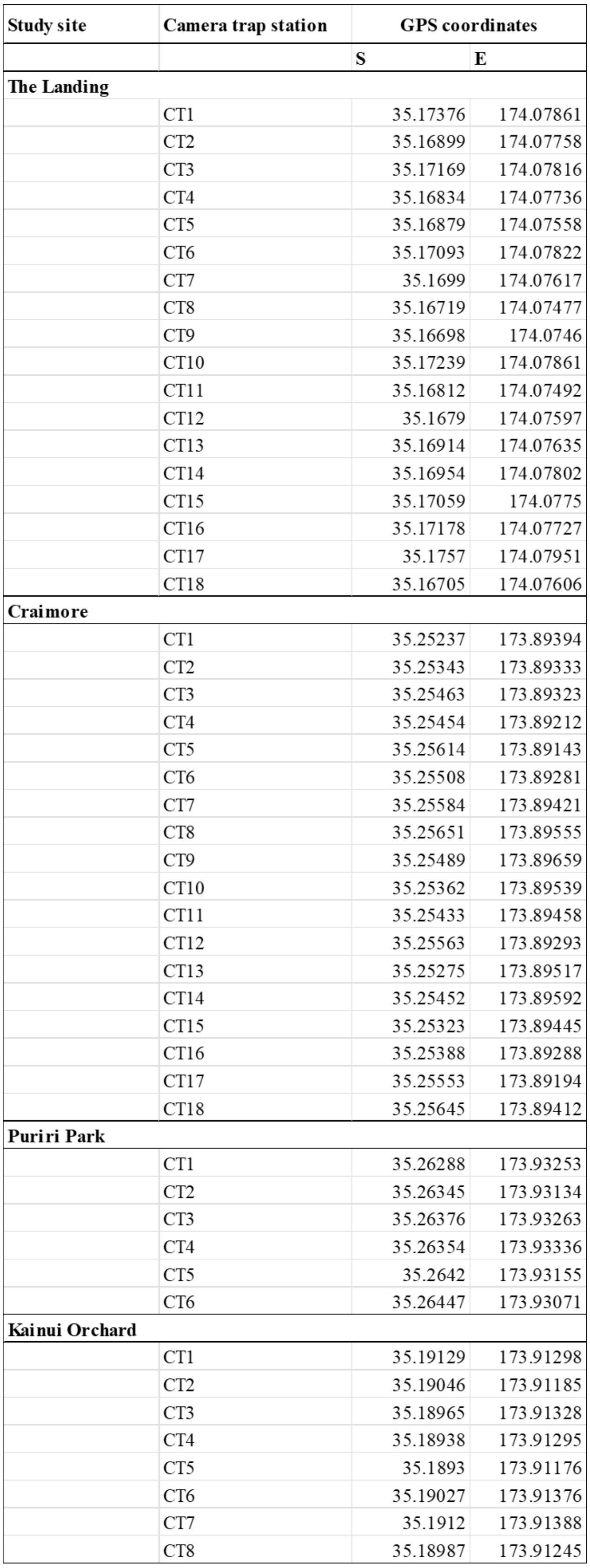
By addressing these questions and examining the habitat use and behaviour of brown kiwi in modified landscapes, this chapter aims to provide insights that can inform conservation efforts and management practices. Such knowledge is vital to ensuring the survival of the brown kiwi in landscapes increasingly shaped by human activity, while identifying opportunities to enhance the ecological compatibility of horticultural systems with kiwi conservation goals.

3.2 Methods

3.2.1 Camera Traps

A total of 50 camera traps were deployed across four study sites: The Landing, Craigmore, Puriri Park, and Kainui Orchard (Table 3.1). The number of cameras per site was based on area, with approximately one camera per hectare to ensure adequate coverage. Within each hectare, cameras were placed in locations representative of the local habitat, typically within orchard or vineyard areas to capture relevant bird activity (Fan, 2023). Cameras were placed proportionally across both orchard interiors and surrounding forest edges, with a focus on orchard areas, as the study aimed to assess kiwi activity specifically within horticultural settings. Specifically, 18 cameras were deployed at The Landing (12 hectares), 18 at Craigmore (12 hectares), six at Puriri Park (6 hectares), and eight at Kainui Orchard (8 hectares).

Table 3.1 The GPS location (decimal degrees format) of camera traps at the four study sites included in this thesis. S = South; E = East.



Study site	Camera trap station	GPS coordinates	
		S	E
The Landing			
	CT1	35.17376	174.07861
	CT2	35.16899	174.07758
	CT3	35.17169	174.07816
	CT4	35.16834	174.07736
	CT5	35.16879	174.07558
	CT6	35.17093	174.07822
	CT7	35.1699	174.07617
	CT8	35.16719	174.07477
	CT9	35.16698	174.0746
	CT10	35.17239	174.07861
	CT11	35.16812	174.07492
	CT12	35.1679	174.07597
	CT13	35.16914	174.07635
	CT14	35.16954	174.07802
	CT15	35.17059	174.0775
	CT16	35.17178	174.07727
	CT17	35.1757	174.07951
	CT18	35.16705	174.07606
Craimore			
	CT1	35.25237	173.89394
	CT2	35.25343	173.89333
	CT3	35.25463	173.89323
	CT4	35.25454	173.89212
	CT5	35.25614	173.89143
	CT6	35.25508	173.89281
	CT7	35.25584	173.89421
	CT8	35.25651	173.89555
	CT9	35.25489	173.89659
	CT10	35.25362	173.89539
	CT11	35.25433	173.89458
	CT12	35.25563	173.89293
	CT13	35.25275	173.89517
	CT14	35.25452	173.89592
	CT15	35.25323	173.89445
	CT16	35.25388	173.89288
	CT17	35.25553	173.89194
	CT18	35.25645	173.89412
Puriri Park			
	CT1	35.26288	173.93253
	CT2	35.26345	173.93134
	CT3	35.26376	173.93263
	CT4	35.26354	173.93336
	CT5	35.2642	173.93155
	CT6	35.26447	173.93071
Kainui Orchard			
	CT1	35.19129	173.91298
	CT2	35.19046	173.91185
	CT3	35.18965	173.91328
	CT4	35.18938	173.91295
	CT5	35.1893	173.91176
	CT6	35.19027	173.91376
	CT7	35.1912	173.91388
	CT8	35.18987	173.91245

3.2.1.1 Camera Deployment and Setup

The camera traps were systematically deployed in a grid pattern across the study sites to monitor bird activity effectively (Fan, 2023). The lenses and sensors of each camera were positioned at least 10 cm above the ground to capture the full height of the North Island brown kiwi. Cameras were oriented toward the ‘inter-row’ areas between vines, and adjustments were made to minimise false triggers caused by shadows during sunrise and sunset, or interference from animals and vegetation. Any obstructions that could block the camera's view or trigger the sensors due to wind movement were removed, provided these adjustments did not damage the crops.

The cameras were equipped with passive infrared sensors and infrared flashes, enabling the detection and recording of nocturnal kiwi activities. The trigger speed was set to ‘Normal’ to accommodate the relatively slow movements of the kiwi. Each camera was programmed to record 20 seconds of video upon detecting movement, with a time delay of 0.6 to 1 second between recordings, depending on the camera brand and model. This setup allowed for a balance between sufficient video length for species and behaviour identification and optimized storage capacity on SD cards, while minimising the frequency of battery replacements. Video quality was set to ‘Ultra’ and motion detection was configured to ‘Long-range’ to maximise kiwi detection.

Two brands of camera types were used: Bushnell Trophy Cam 8MP, Trophy Cam HD Max, Bushnell Aggressor No Glow HD Trophy Cam and older and newer versions of Browning Strike Force Elite HD. Bushnell cameras and newer Browning models operated only during nighttime, with active hours adjusted to seasonal daylight changes. From March to August (autumn and winter), cameras were active from 7:00 p.m. to 5:30 a.m., while from September to February (spring and summer) they operated from

5:30 p.m. to 7:00 a.m. The older Browning cameras recorded continuously over 24 hours, capturing both nocturnal and diurnal species, but resulted in additional false triggers during the daytime.

3.2.1.2 Heat Map Analysis

Heat maps were generated to visually represent camera capture rates across the study sites, highlighting spatial patterns of the North Island brown kiwi activity. Capture rates were illustrated using color-coded circles, with larger circles representing higher rates. The yellow lines marked the boundaries of the research areas, while solid blue lines represented permanent streams, and dashed blue lines indicated temporary streams. Camera trap locations were marked as blue dots on the maps. The spatial visualisation was created using QGIS and Google Earth, which allowed for the precise mapping of camera trap locations and environmental features. Data from camera traps were processed and overlaid onto satellite imagery to ensure accurate spatial representation. These visualisations provided a clear depiction of kiwi activity distribution, facilitating comparisons between different habitat types and identifying potential areas of high activity.

3.2.2 North Island Brown Kiwi Behaviour and Activity Analysis

The categorisation of the North Island brown kiwi behaviours into nine types — walking, foraging, investigating, prey handling, vigilance, comfort, escape, social, and can't tell — was based on the classification system proposed by Fan (2023). The ‘can't tell’ category included videos where behaviour could not be determined due to poor visibility caused by rain, partial visibility of the kiwi, or distance. Each video was assigned at least one behaviour type, and the occurrence rate was used to represent the frequency of each behaviour recorded across all kiwi videos.

Additionally, three videos were excluded from the analysis due to recording errors that made it impossible to determine the capture time; these were categorised as ‘Unknown’ and excluded from the analysis.

3.2.2.1 Field Sampling and Data Collection

Field trips were conducted approximately every one-and-a-half months to replace batteries and collect SD cards, ensuring consistent data collection throughout the sampling period. These trips covered seasonal changes in orchard and vineyard activity, providing a robust dataset for later analysis.

The camera capture rates were analysed for each trap across the four study sites to identify spatial and temporal patterns of kiwi activity. Capture rates were calculated using the formula:

$$Capture\ Rate = \frac{Total\ Number\ of\ Kiwi\ Captures}{Total\ Camera\ Trap\ Nights} \times 100$$

This metric standardises capture frequency and recording duration across locations, enabling meaningful comparisons of kiwi activity. These methods provide a replicable framework for future research on kiwi behaviour in modified environments, offering insights into their adaptability to horticultural landscapes.

3.2.3 Acoustic Recorder Autonomous Recording Units

In this study, five AR4 recorders (Department of Conservation, New Zealand) were used to monitor the calling behaviour of the North Island brown kiwi at the Craigmore study site. These recorders were deployed to identify call times, locations, and calling rates, providing insights into the sex of individuals and the approximate positions of calling birds. This information was intended to contribute to an understanding of the population size and distribution within the study area.

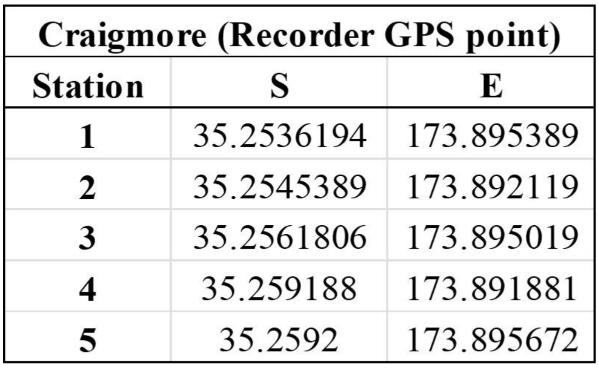
Craigmore was chosen as the study site for the AR4 study due to its confirmed kiwi presence at the start of the study. Additionally, Craigmore featured a single, isolated patch of native bush within a kiwifruit orchard. The isolation of this bush patch was hypothesised to reduce the likelihood of kiwi movement between different bush areas, providing an opportunity to examine the relationship between kiwi activity and orchard proximity.

AR4 recorders were used to estimate the locations of the North Island brown kiwi within the study area. The recorders were strategically placed to ensure overlapping detection ranges (Table 3.2), therefore allowing capture/recapture type analyses and allowing location of kiwi calls and potential movement patterns. The detection range of each recorder is represented by a coloured circle, with overlapping areas indicating regions where calls were simultaneously recorded by multiple devices. The placement of AR4 recorders and their detection ranges are shown in the Recorder Range and Named Region Map (Figure 3.1), following recommendations from Castro et al. (2019) and Juodakis, Castro, and Marsland (2021). The AR4 recorders were strategically placed within the orchard surrounding the native bush to maximise coverage and capture variations in kiwi density as a function of distance from the bush. The placement of recorders at 250-meter intervals ensured overlapping detection ranges within the 300-meter radius recording range of each device. This setup aimed to track kiwi activity across the orchard area while considering the small size of the bush patch, which would not accommodate multiple recorders effectively.

The recorders were mounted on the orchard's kiwifruit trellis system, referred to as 'T-bars,' to ensure clear sound capture and minimise interference from terrain features such as valleys or dense vegetation. Placement was carefully chosen to avoid windy spots, which could introduce noise, and to maximise coverage across the orchard landscape.

- **Recording Schedule:** The recorders operated from 5:00 p.m. to 7:00 a.m. daily, aligning with the nocturnal activity of kiwi, for a total of 14 hours per night.
- **Battery Maintenance:** Each recorder was powered by four AA batteries, which were replaced every 7 to 10 days during regular maintenance visits.
- **Data Collection:** Data collection at Craigmore spanned 42 nights, beginning in June 2024 and concluding in August 2024, with 18 nights of recording in June, 14 nights in July, and 10 nights in August.

Table 3.2. The GPS location (decimal degrees format) of Craigmore acoustic recorders included in this thesis. S = South; E = East.



Craigmore (Recorder GPS point)		
Station	**S**	**E**
1	35.2536194	173.895389
2	35.2545389	173.892119
3	35.2561806	173.895019
4	35.259188	173.891881
5	35.2592	173.895672

In Figure 3.1, each colored circle represents the 300-meter kiwi detection range of an AR4 recorder, with overlapping areas indicating zones where recorders overlapped in range. The regions labelled A–E and their intersections (e.g., AB, ABC, CDE) were used to locate kiwi call detections based on recorder coverage.

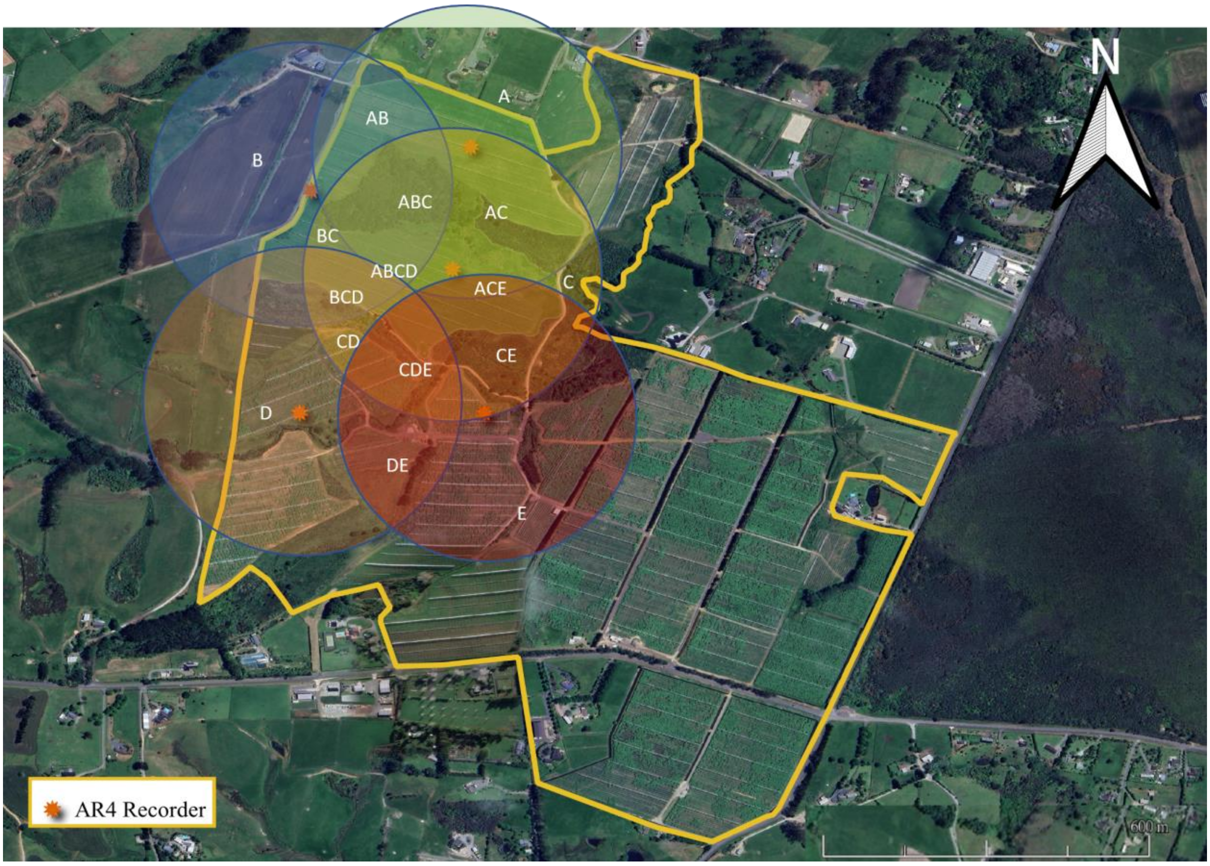


Fig. 3.1. Acoustic recorder Spatial Coverage with Overlapping Detection Regions. The yellow line shows the area of the orchard at Craigmore Orchard. The orange dots are the locations of the five acoustic recorders, each identified by a letter A to E. Each colour represents the 300m radius of coverage for the recorder in its centre. Overlaps in these circles denote overlapping recording areas. Each overlap was labelled with the letters of the recorders that overlapped in coverage at each location.

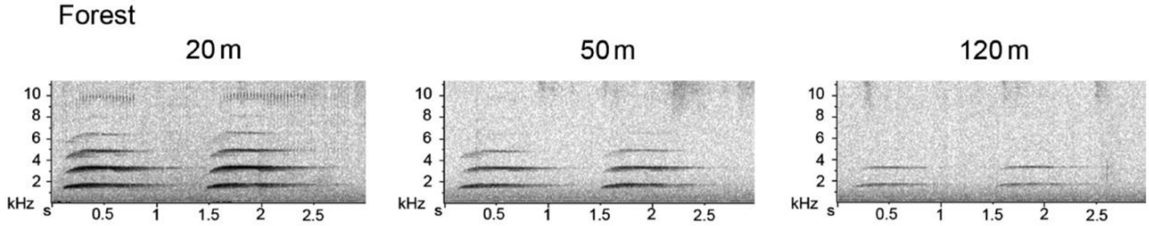
To provide a more detailed understanding of kiwi activity, all usable recordings were categorised based on their location, distinguishing between recordings from orchard and bush areas. This classification enabled a comparative analysis of kiwi activity across different environments within the study sites. By differentiating activity between these habitats, it was possible to examine habitat preferences and behavioural variations in response to orchard conditions versus native bush.

Call Detection and Verification: 1) AviaNZ software (Marsland et al., 2019) was used to automatically detect and classify kiwi calls. 2) A manual review process confirmed each detection and corrected any false positives or added any missing calls.

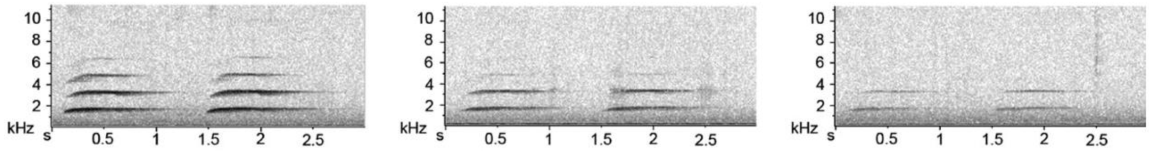
Once calls were confirmed, the following information was recorded in a data sheet:

- **Call Time:** The time each kiwi call occurred relative to sunset (e.g., 1 hour after sunset, 2 hours after sunset, etc.).
- **Call Type:** Recorded kiwi calls were classified into three categories—'Male Alone', 'Female alone', and 'Duet' (when two or more birds call simultaneously or interrupt each other's call).
- **Duet Order:** For duet calls, the sequence of callers was noted as 'Male First' or 'Female First'.
- **Call type (Call ID):** Each male call type was categorised by frequency modulation, number of notes, and the overall shape of the sound curve, as follows (Figure 3.2-3.3):
    - **Type A:** Starts with a sharp increase in frequency, followed by a series of evenly spaced, high-pitched notes that gradually fade.
    - **Type B:** A smooth sequence of evenly spaced notes with minimal variation in frequency.
    - **Type C:** Begins with an irregular pattern before transitioning into a structured sequence, with slight fluctuations in pitch.
    - **Type D:** A two-part call with an initial sharp rise in frequency, followed by a sudden drop.
    - **Type E:** A steady, continuous call with minimal fluctuation and a consistent intensity.

- **Type F:** Scattered, irregular harmonic bands with fragmented or faded tonal elements, often affected by distance.



(a) Recorders in front of the speakers



(b) Recorders behind the speakers

Figure 3.2 Degradation of a male brown kiwi call as it travels through the forest from the source to the recorder. Reprinted with permission from the authors (Priyadarshani et al, 2018).

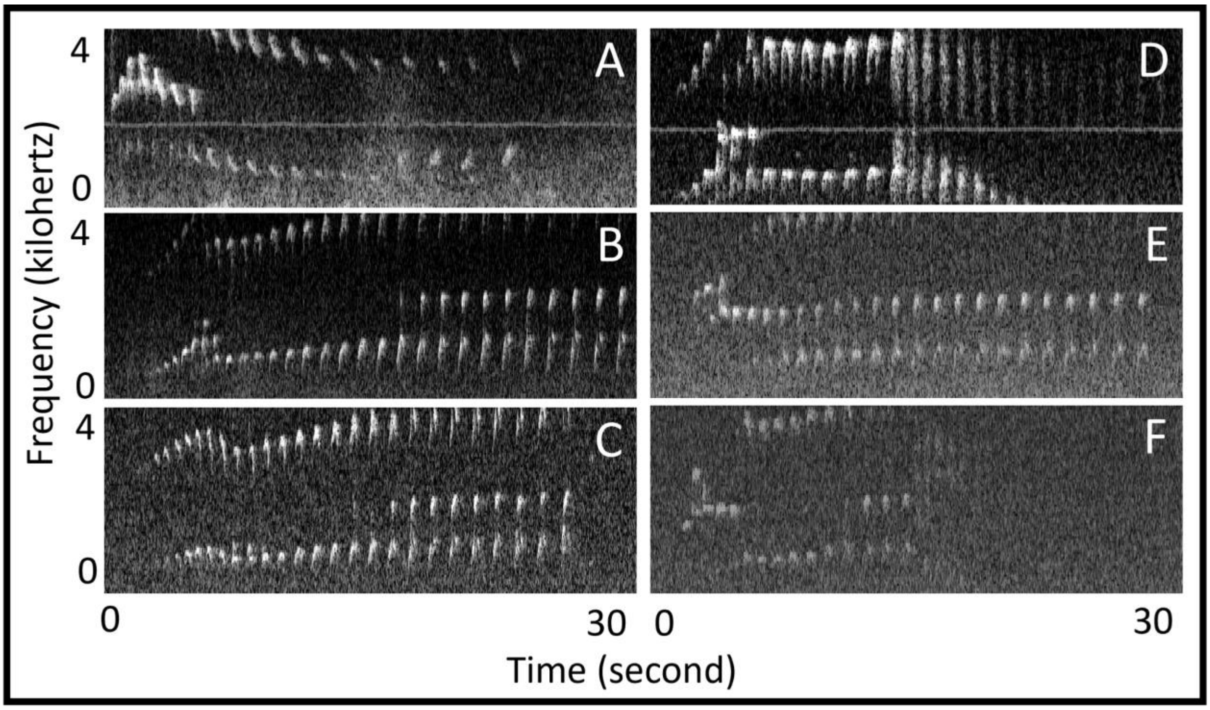


Figure 3.3. Male call types (A, B, C, D, E, and F) found in this study

Kiwi calls were separated and analysed based on their time of detection and spatial distribution across the recorder network. To do this, first calls occurring within a 10-

minute interval at different recorders were considered potential detections of the same individual or a kiwi pair in the case of duets. This was confirmed by visual observation of the calls. Calls that looked and sounded the same within this range were considered the same call.

To estimate the distance and location of kiwi calls, I followed the method described by Priyadarshani, Castro, and Marsland (2018; Figure 3.2). Their method uses the quality of the call at each recorder to triangulate the source location, with better spectrograms obtained for calls closer to a recorder. I organised and adjusted time differences between recorders using Excel to identify consistent patterns. By comparing spectrogram quality across recorders, I estimated the likely origin of each call on the map. While this approach provides a reasonable estimate of calling locations, it does not offer precise directional information. Determining the exact direction of the call remains challenging due to background noise and the fixed placement of recording devices.

Calls were assigned to specific regions in the orchard (A–E) shown on the Recorder Range and Named Region Map (Figure 3.1). This methodology, combined with the analysis of call times, types, and patterns, provided a comprehensive understanding of kiwi activity and distribution across the Craigmore study site. The integration of recorder data with the acoustic recorder spatial coverage with overlapping detection regions (Figure 3.1) allowed for spatial mapping of kiwi movements and habitat use patterns. By categorising kiwi activity in both bush and orchard settings, this study offers insights into potential behavioural adaptations in modified landscapes. The results are expected to contribute valuable information to conservation strategies, particularly in understanding how kiwi interact with agricultural environments and whether these modified habitats support their ecological needs.

3.2.4 Statistical Analyses

I calculated capture rates based on the videos recorded in orchards and bush areas to analyse kiwi activity. Capture rates were calculated for each orchard and month (due to seasonal variations in kiwi activity). Mean capture rates of kiwi foraging and prey handling behaviours at each study site. These calculations help assess how habitat type and seasonal changes affect kiwi activity patterns. This analysis allowed for an estimation of the kiwi population density in Craigmore, providing insights into how kiwi use orchard environments compared to natural bush habitats. By comparing capture rates across different sites, seasons, and behaviours (foraging vs. prey handling), I was able to evaluate habitat preferences and key factors influencing kiwi activity in orchards.

To estimate the density of the North Island brown kiwi in the study area, I used a spatial capture–recapture (SCR) model (Juodakis et al., 2021). This technique is widely used in ecological studies to estimate population densities of elusive and cryptic species. It calculates individual detection probabilities based on the spatial location of capture, providing more reliable estimates of population size than traditional mark-recapture methods. Given the nocturnal and cryptic nature of kiwi, SCR modelling is particularly useful as it allows for population estimates based on acoustic data without the need for direct physical capture.

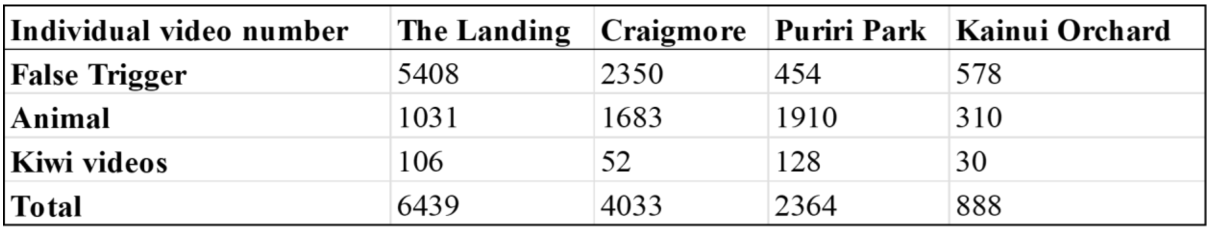
3.3 Results

3.3.1 Camera Traps

A total of 13,724 videos were captured across the four study sites during the period of the study (106 nights) and of those videos, 4,934 (36%) were of animals. Table 3.3

presents an overview of the camera trap results collected from four study sites: The Landing, Craigmore, Puriri Park, and Kainui Orchard. The Landing recorded the highest number of total triggers, with 6,439 individual events, of which 84.0% were classified as false triggers and 16.0% as animal detections. Among the animal detections, 106 videos were confirmed to contain the North Island brown kiwi. At Craigmore, 58.3% were categorised as false triggers and 41.7% as animal detections. Of these, 52 videos were identified as containing the North Island brown kiwi. In Puriri Park, 19.2% were classified as false triggers and 80.8% as animal detections. This site recorded 128 videos containing the North Island brown kiwi, the highest number among the four study sites. Kainui Orchard comprised 65.1% false triggers and 34.9% animal detections. Only 30 videos from this site featured the North Island brown kiwi. The duration of camera monitoring varied across sites, with Puriri Park having the most nights (176), followed by Craigmore (172), The Landing (146), and Kainui Orchard (112).

Table 3.3 Overview of camera trap results in four study sites



Individual video number	The Landing	Craigmore	Puriri Park	Kainui Orchard
False Trigger	5408	2350	454	578
Animal	1031	1683	1910	310
Kiwi videos	106	52	128	30
Total	6439	4033	2364	888

Camera trap monitoring across the four study sites captured a total of 30 species, consisting of 9 mammal species and 21 bird species, presented in Table 3.4 by orchard and native status. Results of species captured were analysed, providing an overview of mammal and bird species composition at these locations, offering insights into the biodiversity and ecological dynamics of these horticultural environments.

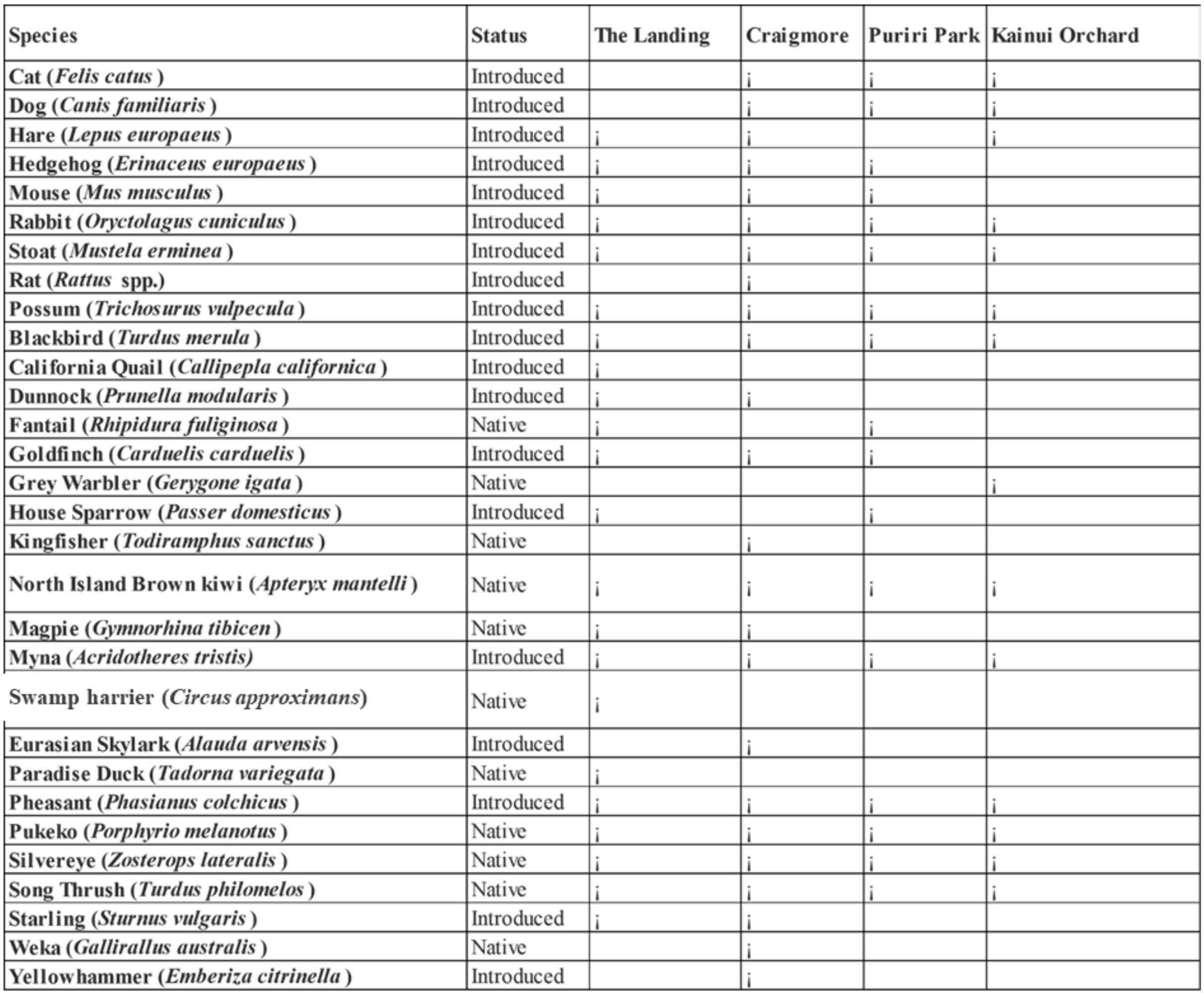
Understanding the ecological dynamics aids in biodiversity of these environments, aiding in biodiversity monitoring and management efforts.

Among the mammals, cats, rabbits and rats were found at all four locations. This, and their consistent documentation at horticultural sites, shows their wide distribution and successful adaptation to these environments. Dogs were recorded at The Landing, Craigmore, and Puriri Park. Hares were observed at The Landing, Craigmore, and Kainui Orchard, while hedgehogs were present at The Landing, Craigmore, and Puriri Park. Stoats were found only at Craigmore, showing a more limited distribution, while possums were observed at all four sites, highlighting their adaptability across these environments.

For bird species, blackbirds, kiwi, mynahs, pheasants, pukeko, silvereyes, and song thrushes were recorded at all four locations, demonstrating their widespread presence. California quails, New Zealand falcons, and paradise ducks were only found at The Landing, indicating their specific occurrence in this particular environment. Dunnocks were observed at both The Landing and Craigmore, while fantails were present at The Landing and Puriri Park. Kingfishers were recorded only at Craigmore, suggesting a unique presence in that specific site. Other species, including the yellowhammer and grey warbler, were observed only at Craigmore. Weka was also recorded only at Craigmore, emphasising the unique avian community at this location.

House sparrows were found at The Landing and Puriri Park, showing a partial distribution across the environments. Goldfinches were observed at The Landing, Craigmore, and Puriri Park, indicating their adaptability to multiple environments but were absent from Kainui Orchard. Starlings were present at The Landing and Craigmore, such as the Australasian harriers, were occasionally observed at specific locations. Yellowhammers were only found at Craigmore, further highlighting the unique bird species composition at this site.

Table 3.4 Presence and status of native and introduced species captured across four study sites. i = present

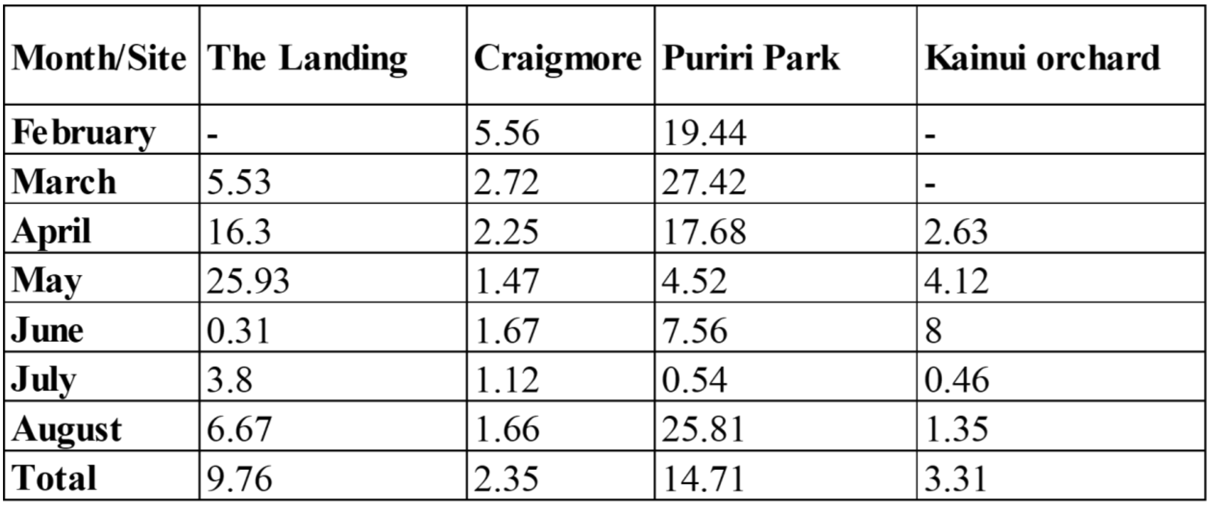


Species	Status	The Landing	Craigmore	Puriri Park	Kainui Orchard
Cat (*Felis catus*)	Introduced		¡	¡	¡
Dog (*Canis familiaris*)	Introduced		¡	¡	¡
Hare (*Lepus europaeus*)	Introduced	¡	¡		¡
Hedgehog (*Erinaceus europaeus*)	Introduced	¡	¡	¡	
Mouse (*Mus musculus*)	Introduced	¡	¡	¡	
Rabbit (*Oryctolagus cuniculus*)	Introduced	¡	¡	¡	¡
Stoat (*Mustela erminea*)	Introduced	¡	¡	¡	¡
Rat (*Rattus* spp.)	Introduced		¡		
Possum (*Trichosurus vulpecula*)	Introduced	¡	¡	¡	¡
Blackbird (*Turdus merula*)	Introduced	¡	¡	¡	¡
California Quail (*Callipepla californica*)	Introduced	¡			
Dunnock (*Prunella modularis*)	Introduced	¡	¡		
Fantail (*Rhipidura fuliginosa*)	Native	¡		¡	
Goldfinch (*Carduelis carduelis*)	Introduced	¡	¡	¡	
Grey Warbler (*Gerygone igata*)	Native				¡
House Sparrow (*Passer domesticus*)	Introduced	¡		¡	
Kingfisher (*Todiramphus sanctus*)	Native		¡		
North Island Brown kiwi (*Apteryx mantelli*)	Native	¡	¡	¡	¡
Magpie (*Gymnorhina tibicen*)	Native	¡	¡		
Myna (*Acridotheres tristis)*	Introduced	¡	¡	¡	¡
Swamp harrier (*Circus approximans*)	Native	¡			
Eurasian Skylark (*Alauda arvensis*)	Introduced		¡		
Paradise Duck (*Tadorna variegata*)	Native	¡			
Pheasant (*Phasianus colchicus*)	Introduced	¡	¡	¡	¡
Pukeko (*Porphyrio melanotus*)	Native	¡	¡	¡	¡
Silvereye (*Zosterops lateralis*)	Native	¡	¡	¡	¡
Song Thrush (*Turdus philomelos*)	Native	¡	¡	¡	¡
Starling (*Sturnus vulgaris*)	Introduced	¡	¡		
Weka (*Gallirallus australis*)	Native		¡		
Yellowhammer (*Emberiza citrinella*)	Introduced		¡		

3.3.1.1 North Island Brown Kiwi Capture Rates in Videos by Study Sites and Season

Puriri Park recorded the highest overall kiwi capture rate, with 27.42 in March and 25.81 in August as the peak months (Table 3.5). In contrast, Kainui Orchard consistently showed the lowest capture rates, with the highest rate being 8.00 in June. Craigmore displayed moderate rates across all months, with the highest capture rate of 5.56 recorded in February. The Landing exhibited a gradual increase from March (5.53) to May (25.93), followed by a decline in subsequent months. At The Landing, camera traps were not deployed in February, and similarly, no cameras were set up in February or March at Kainui Orchard; hence these entries are marked with a dash (-). The values in the table represent camera capture rates for kiwi videos.

Table 3.5. Kiwi videos capture rate (per camera per night) in each site and month.



Month/Site	The Landing	Craigmore	Puriri Park	Kainui orchard
February	-	5.56	19.44	-
March	5.53	2.72	27.42	-
April	16.3	2.25	17.68	2.63
May	25.93	1.47	4.52	4.12
June	0.31	1.67	7.56	8
July	3.8	1.12	0.54	0.46
August	6.67	1.66	25.81	1.35
Total	9.76	2.35	14.71	3.31

At The Landing, the bush area recorded the highest capture rate at 43.72, compared to a much lower rate of 1.66 in the orchard area. Similarly, Craigmore showed a higher capture rate in the bush area (9.03) than in the orchard area (0.40). In contrast, Puriri Park recorded a higher capture rate in the orchard area (16.64) compared to the bush area (6.87). At Kainui Orchard, all kiwi videos were captured in the bush area, with a rate of 10.71, while no videos were recorded in the orchard area (Figure 3.4).

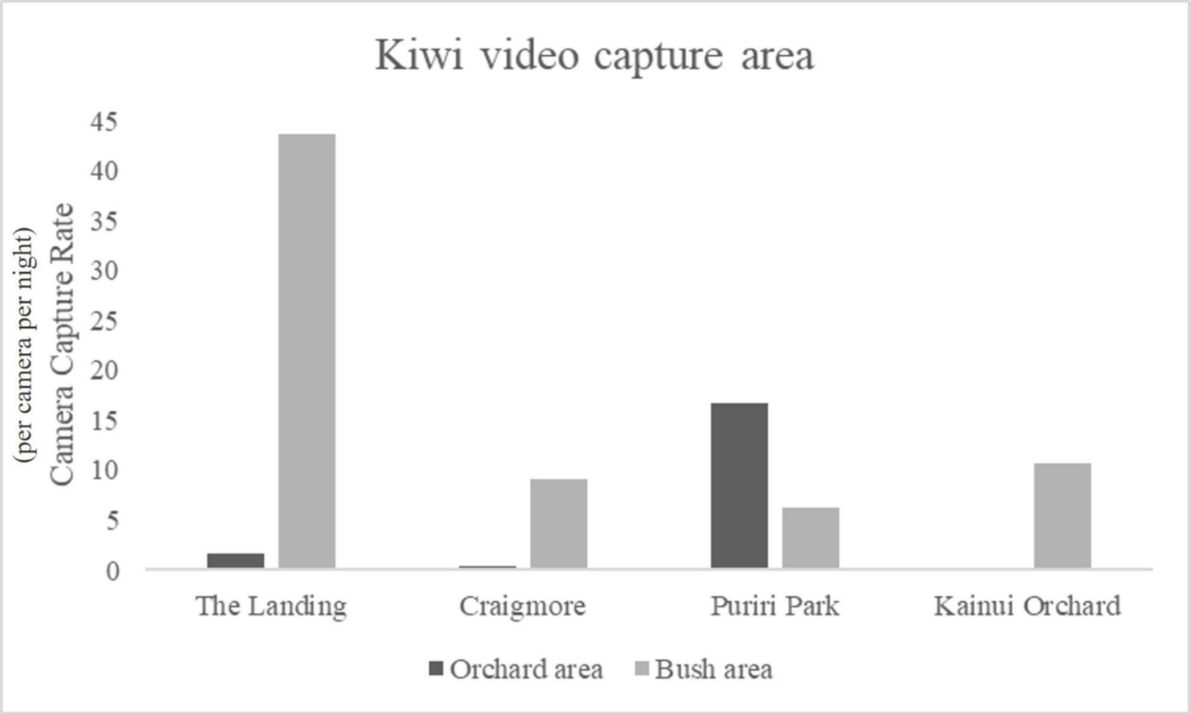


Fig. 3.4 Variation in capture rates between orchard and bush areas across different sites

When considering the overall camera capture rates across all four study sites, Puriri Park had the highest camera capture rate, while Craigmore had the lowest (Figure 3.5).

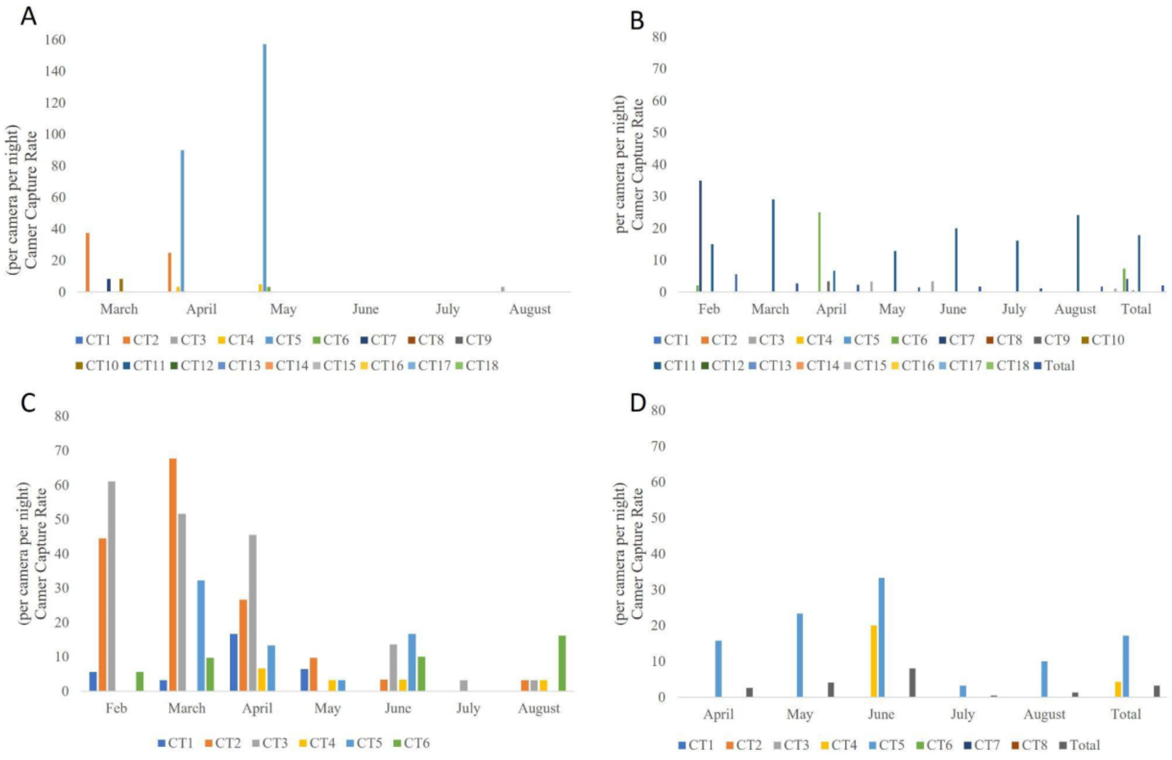


Figure 3.5 Camera trap seasonal video capture rate at the study sites. A. The Landing; B. Craigmore; C. Kainui; D. Puriri Park. CT = camera trap station; Please notice the difference in axis size between The Landing and the other sites

3.3.1.2 Habitat utilisation using Heatmaps from Camera Trap Capture Rates

At The Landing, the highest kiwi capture rates were recorded at CT2, CT7, and CT10, with CT2 and CT10 positioned in the bush area near the main road (Figure 3.6). In Craigmore, CT11 and CT6 had the highest capture rates, both located in the bush. At Puriri Park, CT3, situated in the orchard, recorded the highest capture rate, indicating notable kiwi activity in a horticultural setting. In Kainui Orchard, CT5 had the highest capture rate, aligning with the bush-related trends observed at other sites.

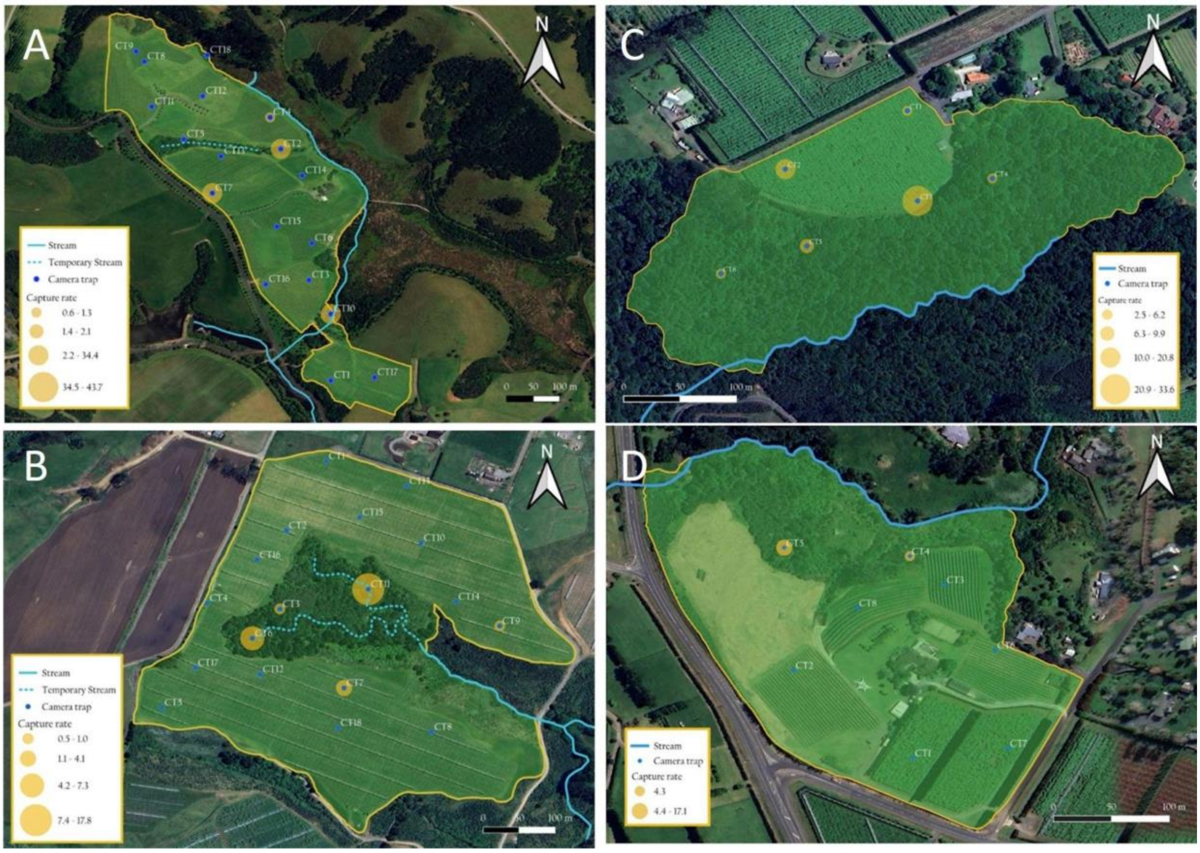


Fig. 3.6 Overview of spatial variation in kiwi activity across the different study sites. A. The Landing; B. Craigmore; C. Kainui; D. Puriri Park. CT = camera trap station. Each heat map displays the capture rates using colour-coded circles, with larger circles representing higher capture rates.

3.3.1.3 Pattern of North Island Brown Kiwi activity time at each site

The analysis of the North Island brown kiwi video capture times across the four study sites highlights notable variations in activity patterns. A total of 234 kiwi videos were analysed, excluding repeated captures of the same individual within 30 minutes at the same location, following the methodology outlined by Brook et al. (2012).

Overall, kiwi activity was consistently higher in bush areas compared to orchard areas across all periods (Figure 3.7). Notably, no kiwi videos were captured in the orchard area of Kainui Orchard, emphasising the limited activity of kiwi in this type of environment. This distinction between bush and orchard areas provides insights into the habitat preferences of the North Island brown kiwi across the study sites.

The highest capture rate in bush areas was observed 9 hours after sunset, with a rate of 0.95 kiwi videos/100 hours. In contrast, the orchard areas recorded their highest capture rate during the first hour after sunset, at 0.18 videos/100 hours. Throughout the monitoring period, the bush areas demonstrated significantly higher capture rates than the orchard areas, with values ranging from 0.23 to 0.95 in the bush and from 0 to 0.25 in the orchards. This highlights a marked difference in kiwi activity patterns between the two habitat types.

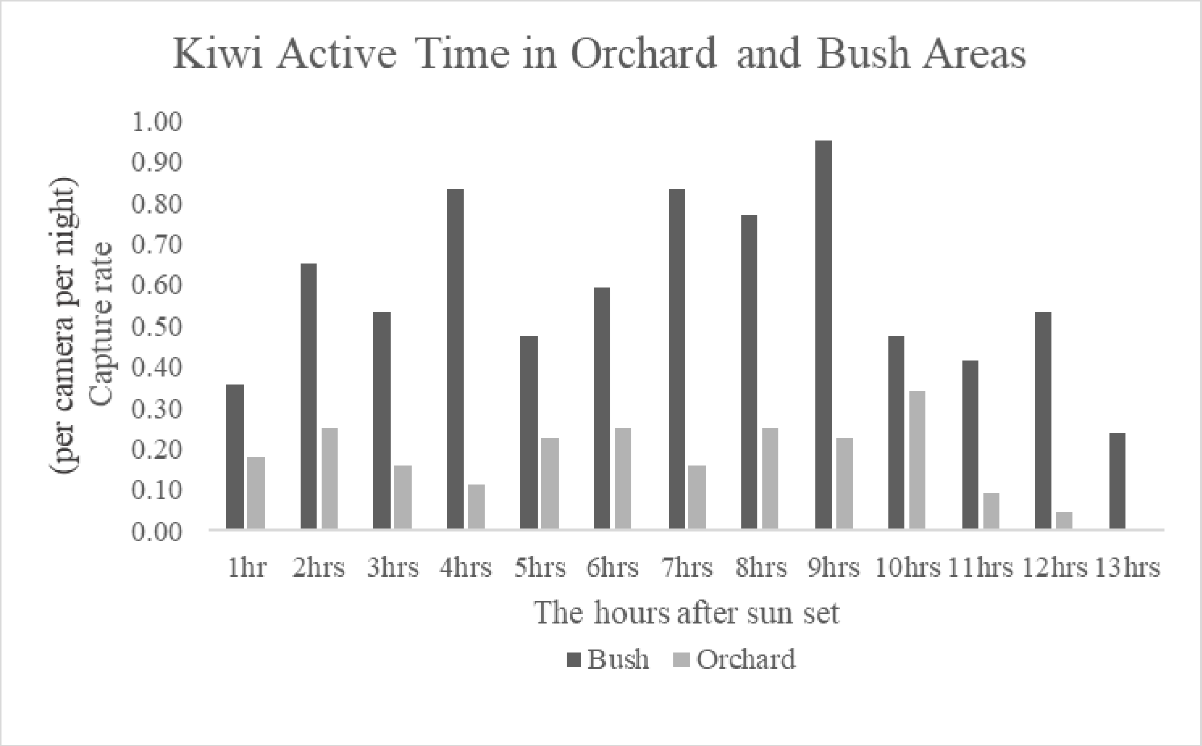


Fig. 3.7 Overall camera capture rates of the North Island brown kiwi activity in orchard and bush areas over the 13 hours following sunset.

Kiwi activity was higher in kiwifruit orchards compared to vineyards across most time periods. The peak capture rate in kiwifruit orchards occurred during the 9th hour after sunset, with a rate of 0.47, while the highest capture rate in vineyards was recorded during the 5th hour, at 0.41. In kiwifruit orchards, capture rates ranged from 0.03 to 0.5, whereas in vineyards, rates ranged from 0.1 to 0.4. This demonstrates differing patterns of kiwi activity between the two habitat types (Figure 3.8).

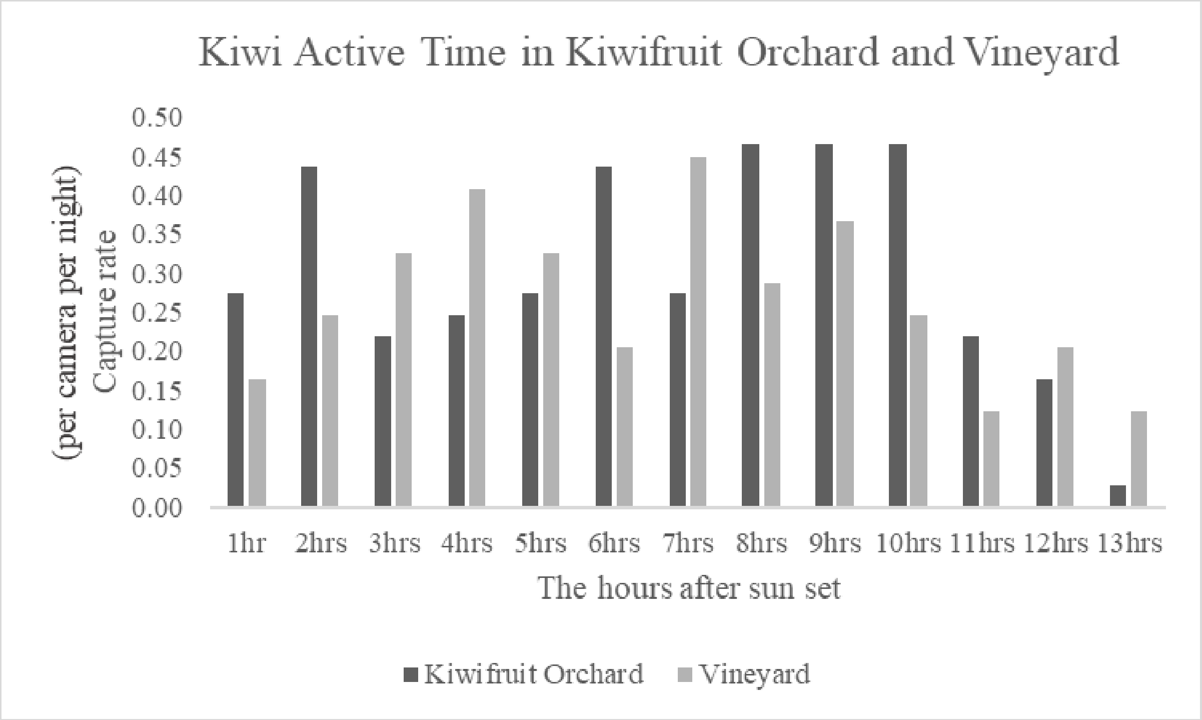


Fig. 3.8 Camera capture rates of the North Island brown kiwi in kiwifruit orchards and vineyards during the 13 hours following sunset.

Overall, the highest capture rates were observed in summer, with a peak of 1.31 during the first hour after sunset (Figure 3.9). In autumn, capture rates were generally lower than in summer, peaking at 0.71 during the 9th hour. Winter showed the lowest activity levels, with a maximum capture rate of 0.15 during the 2nd hour after sunset. Across all seasons, kiwi activity tended to decline after the 9th hour, with minimal capture rates recorded during the 12th and 13th hours. These results highlight seasonal variations in kiwi activity patterns, as reflected in the capture rates.

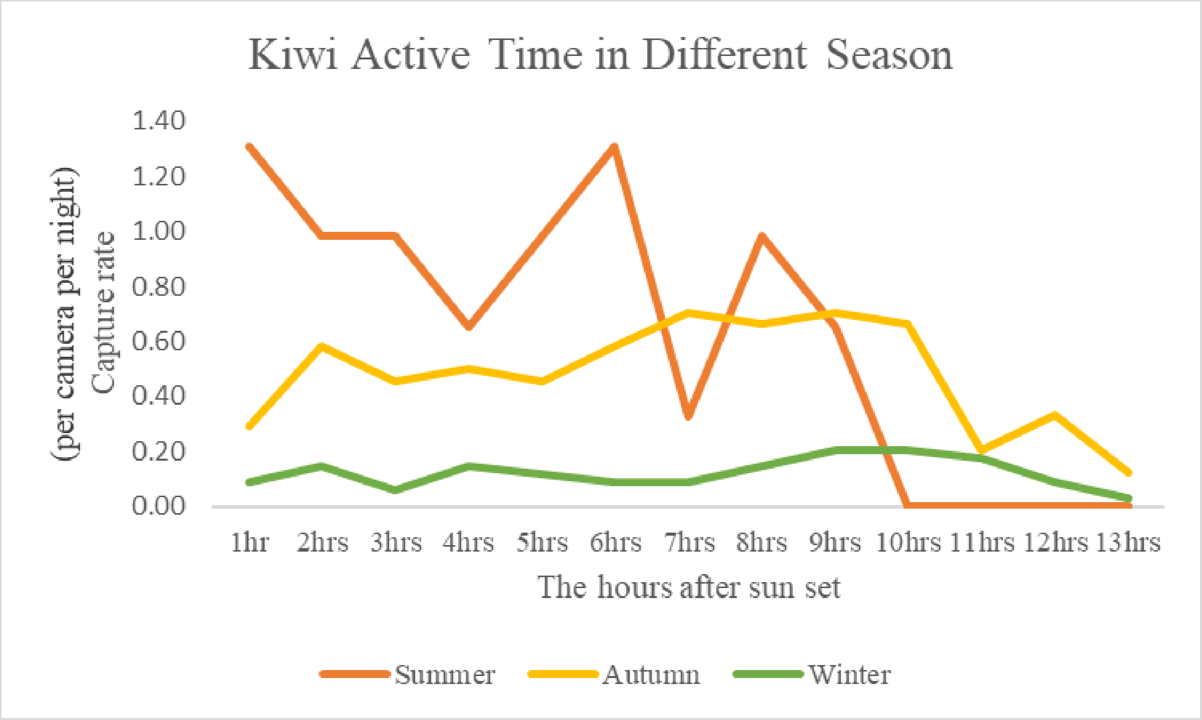


Fig. 3.9 Camera capture rates of the North Island brown kiwi activity during the 13 hours following sunset across three different seasons: summer, autumn, and winter.

3.3.1.4 North Island Brown Kiwi Behaviour Type Composition

Across all videos from the four study sites, the most common behaviour type recorded was Walking, followed by Foraging (Figure 3.10). In the forest areas, the most frequently observed behaviours were Walking and Foraging, with Can’t Tell being the least common. In the orchard areas, Foraging was the most common behaviour, followed by Walking, with Can’t Tell remaining the least observed behaviour.

Site-Specific Behaviour Patterns (Figure 3.11):

- The Landing: The most common behaviour was Walking, followed by Foraging, while the least observed behaviour was Social. In forest areas, Walking and Foraging were most common, with Social as the least common type. In orchard areas, Walking was the most frequent, followed by Foraging, while Comfort and Social behaviours were the least common.

- Craigmore: Foraging was the predominant behaviour, followed by Prey Handling, with Social and Vigilance being the least common. This pattern was consistent across both forest and orchard areas, with Foraging as the most common behaviour and Prey Handling as the second.
- Puriri Park: Walking was the most common behaviour, followed by Foraging. This pattern was observed in both forest and orchard areas, although Foraging was more common in orchards, with Walking as the second most frequent.
- Kainui Orchard: Walking was the most observed behaviour, followed by Foraging. In forest areas, Walking and Foraging remained the top behaviours, and in orchard areas, Foraging was the most frequent, with Walking as the second.

When focusing specifically on Foraging behaviour, the results show that in The Landing, Craigmore, and Kainui Orchard, more videos captured kiwis foraging in bush areas than in orchard areas. Puriri Park was the only study site where kiwi foraging behaviour was more frequently observed in orchard areas than in bush areas.

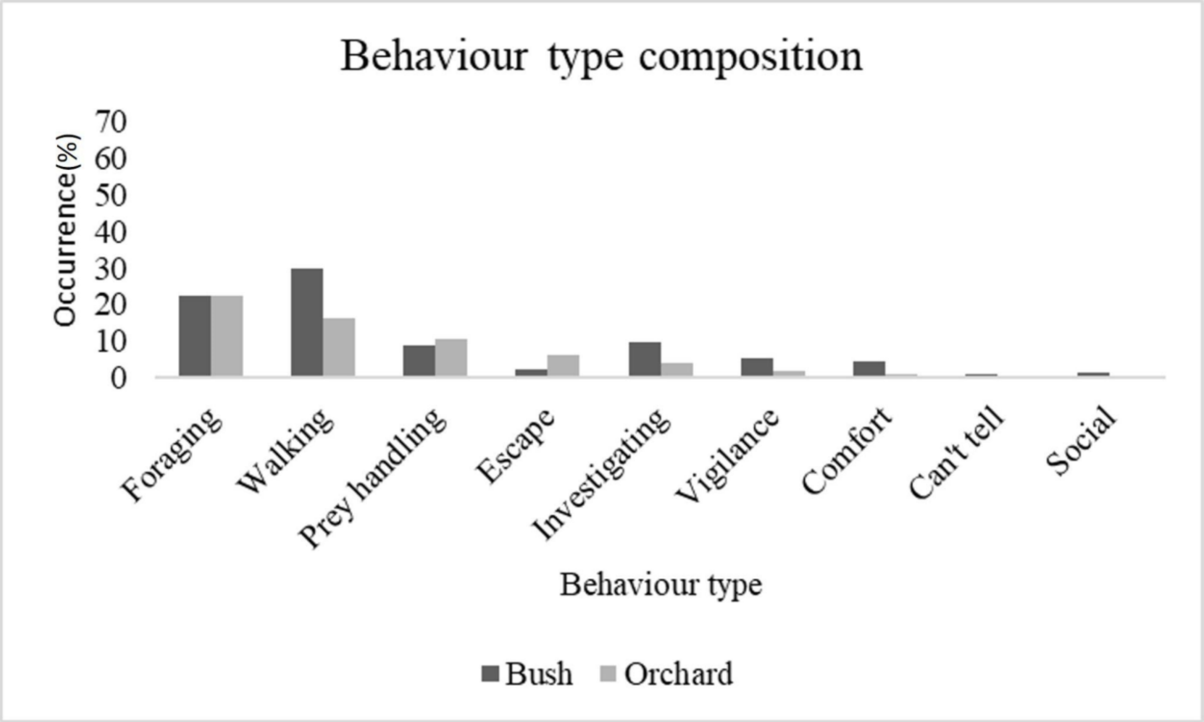


Fig. 3.10 North Island brown kiwi behaviour type composition in total- orchard v.s bush

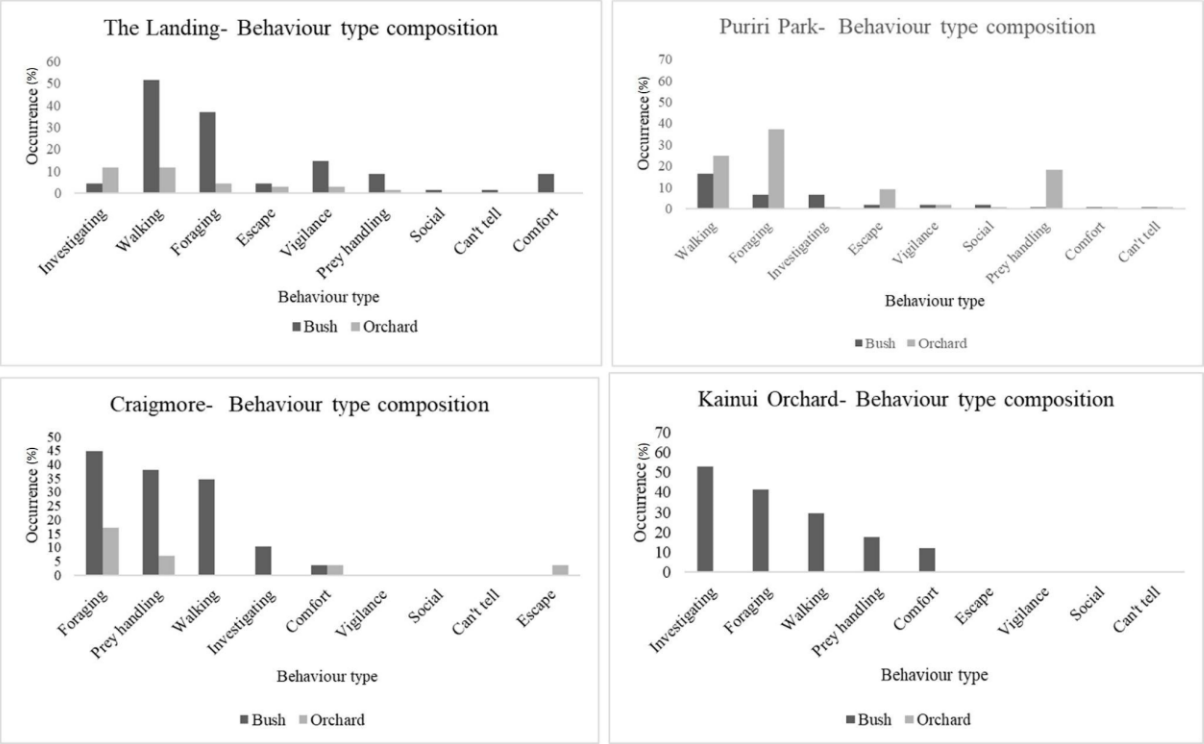


Fig. 3.11 North Island brown kiwi behaviour type composition- orchard v.s bush in each study site

3.3.1.5 Use of orchard area for foraging by North Island Brown Kiwi

This section focuses specifically on the foraging activity of the North Island brown kiwi, as this is a key measure of the value of orchards to kiwi as feeding habitats and where the ecosystem service provided by kiwi to orchards can be observed. To ensure consistency in data analysis, the average video length for each site was calculated, confirming no significant differences in video durations across the study sites. To assess the foraging success rate of the North Island brown kiwi, the average camera capture rate (CTR) for foraging behaviours was calculated at each study site. Additionally, the average CTR for prey handling was analysed to provide further insights into foraging efficiency. By combining the results of the average CTRs for both foraging and prey handling, this study aims to present a comprehensive understanding of the foraging success of the North Island brown kiwi in horticultural settings.

The analysis of the average camera capture rate (CTR) for foraging behaviours of the North Island brown kiwi revealed that, overall, the average CTR was higher in forest areas across the four study sites. Specifically:

- **The Landing**: The average CTR for foraging was higher in forest areas compared to orchard areas.
- **Craigmore**: Forest areas recorded a higher average CTR for foraging.
- **Puriri Park**: Orchard areas showed a higher average CTR for foraging than forest areas.
- **Kainui Orchard**: The average CTR for foraging was higher in the forest area, as no foraging videos were captured in the orchard area.

Similarly, the analysis of average CTR for prey handling behaviours showed a consistent pattern of higher activity in forest areas across the study sites:

- **The Landing**: The average CTR for prey handling was higher in forest areas compared to orchard areas.
- **Craigmore**: Forest areas recorded a higher average CTR for prey handling.
- **Puriri Park**: Orchard areas had a higher average CTR for prey handling than forest areas.
- **Kainui Orchard**: The average CTR for prey handling was higher in the forest area, as no prey handling videos were captured in the orchard area.

These findings illustrate differences in foraging and prey handling behaviours across the study sites, highlighting variations in habitat use between forest and orchard areas (Figures 3.12 - 3.16).

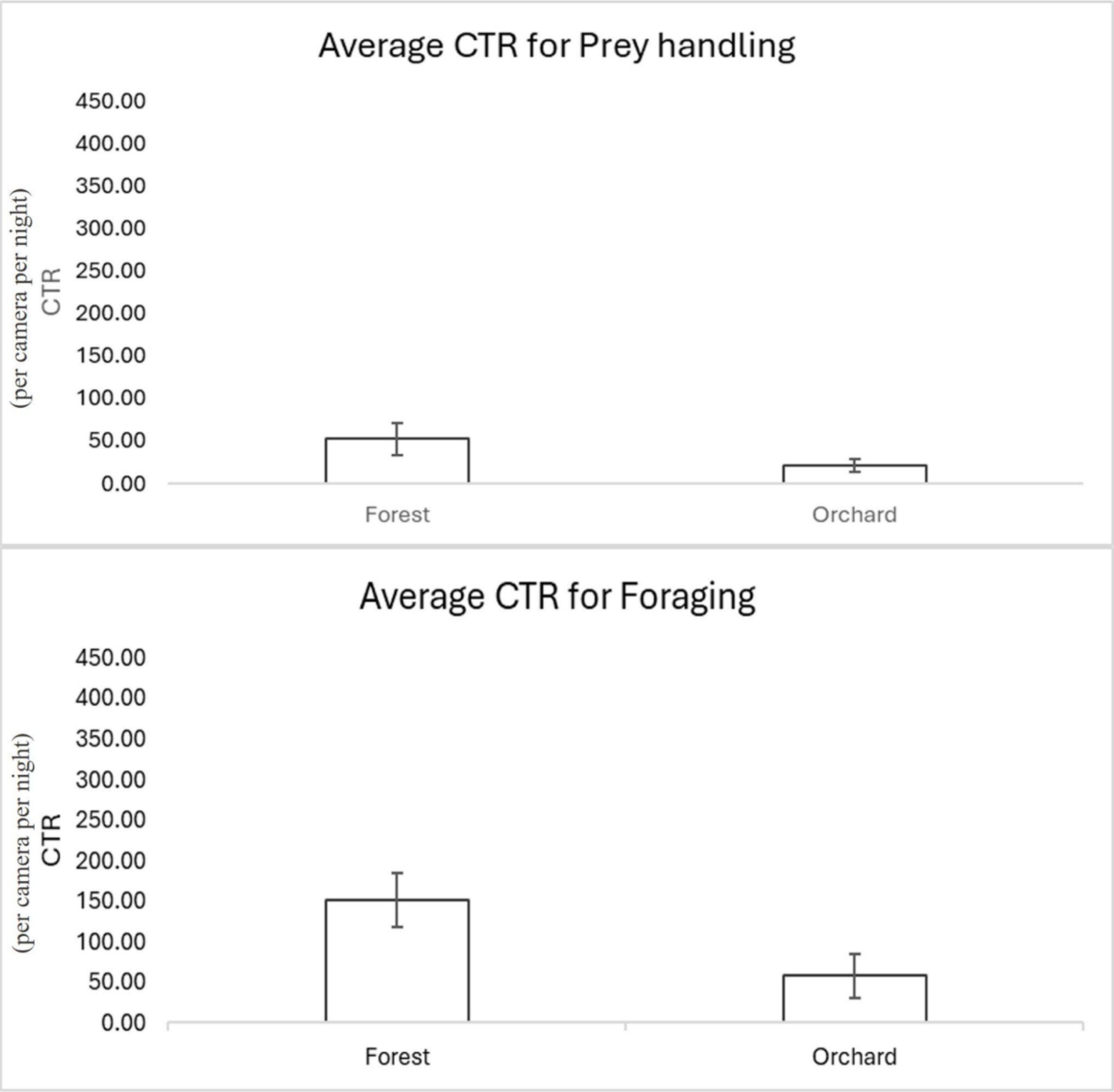


Fig. 3.12 Kiwi average camera capture rate for foraging vs. prey handling

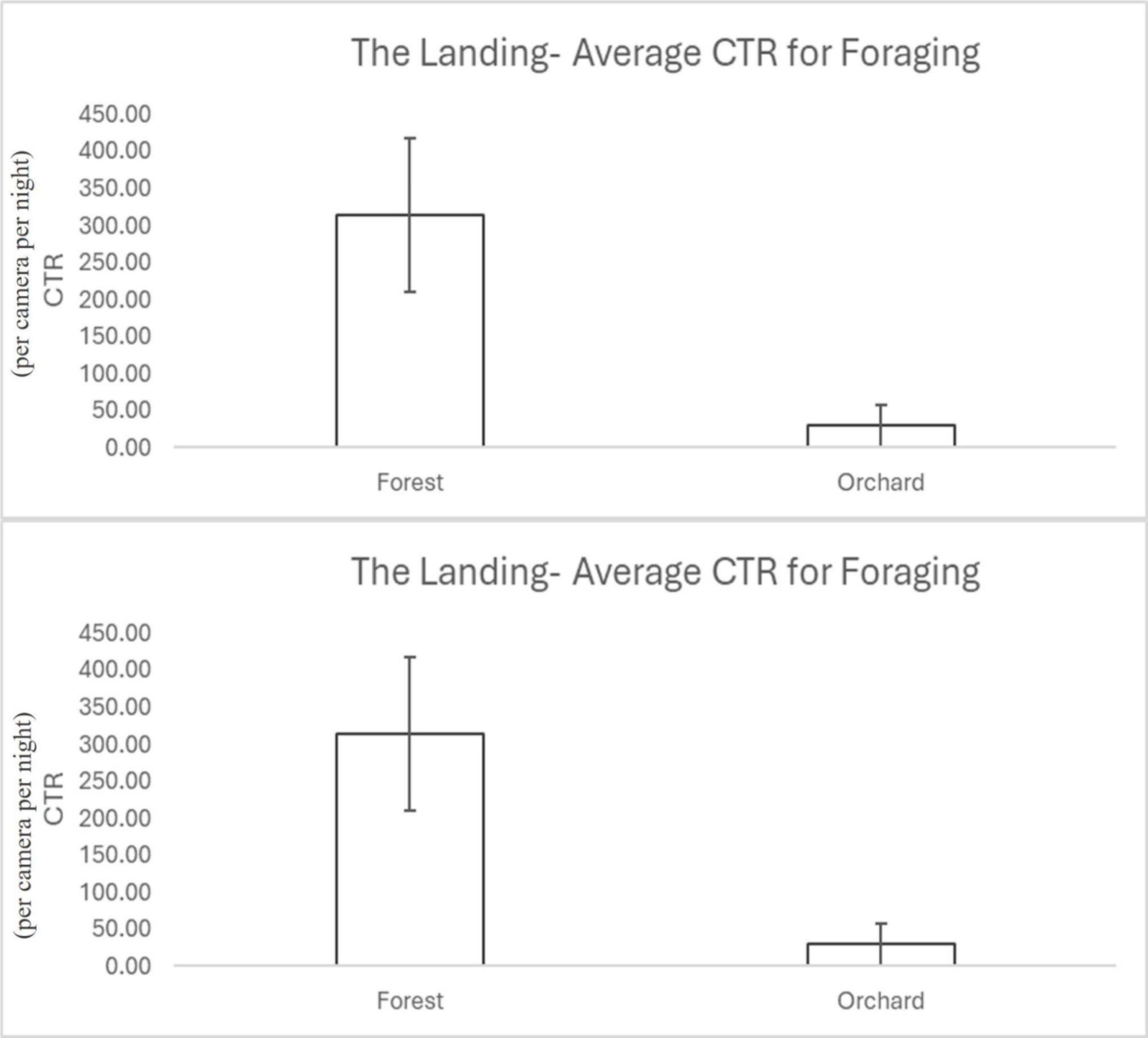


Figure 3.13 Kiwi average camera capture rate for foraging vs. prey handling- the Landing

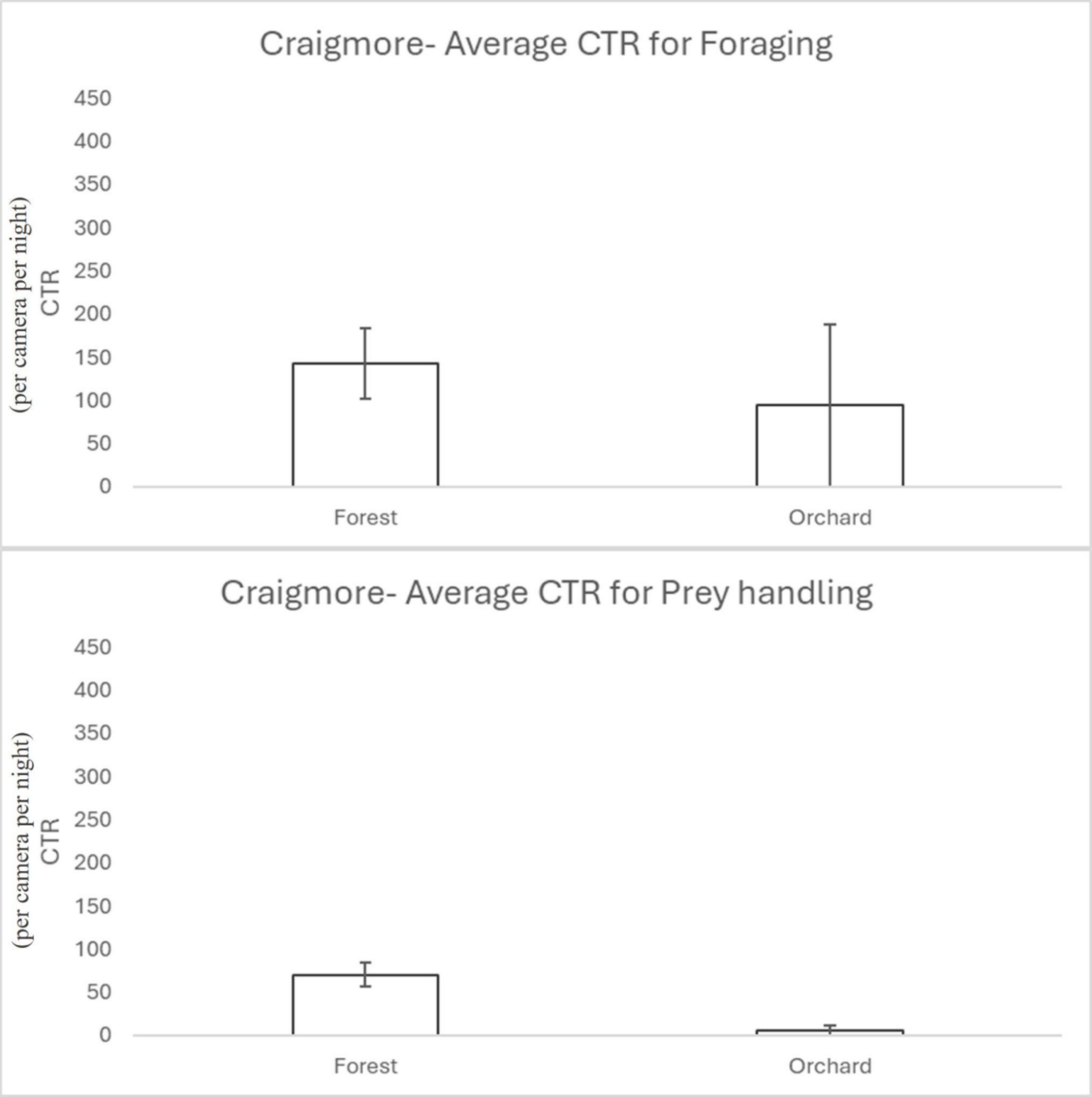
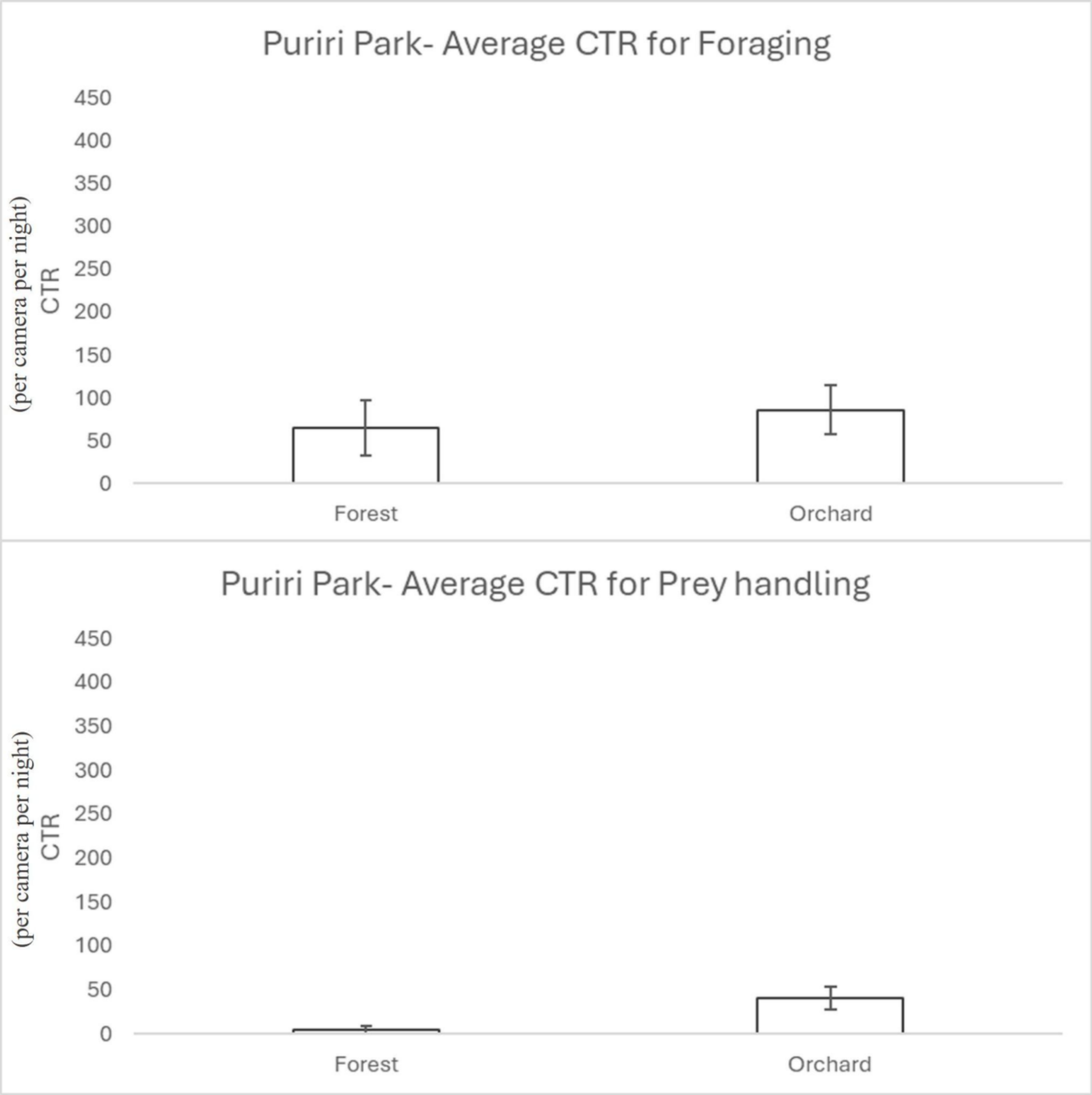


Figure 3.14 Kiwi average camera capture rate for foraging vs. prey handling-Craigmore



Puriri Park- Average CTR for Foraging

Puriri Park- Average CTR for Prey handling

Figure 3.15 Kiwi average camera capture rate for foraging vs. prey handling- Puriri Park

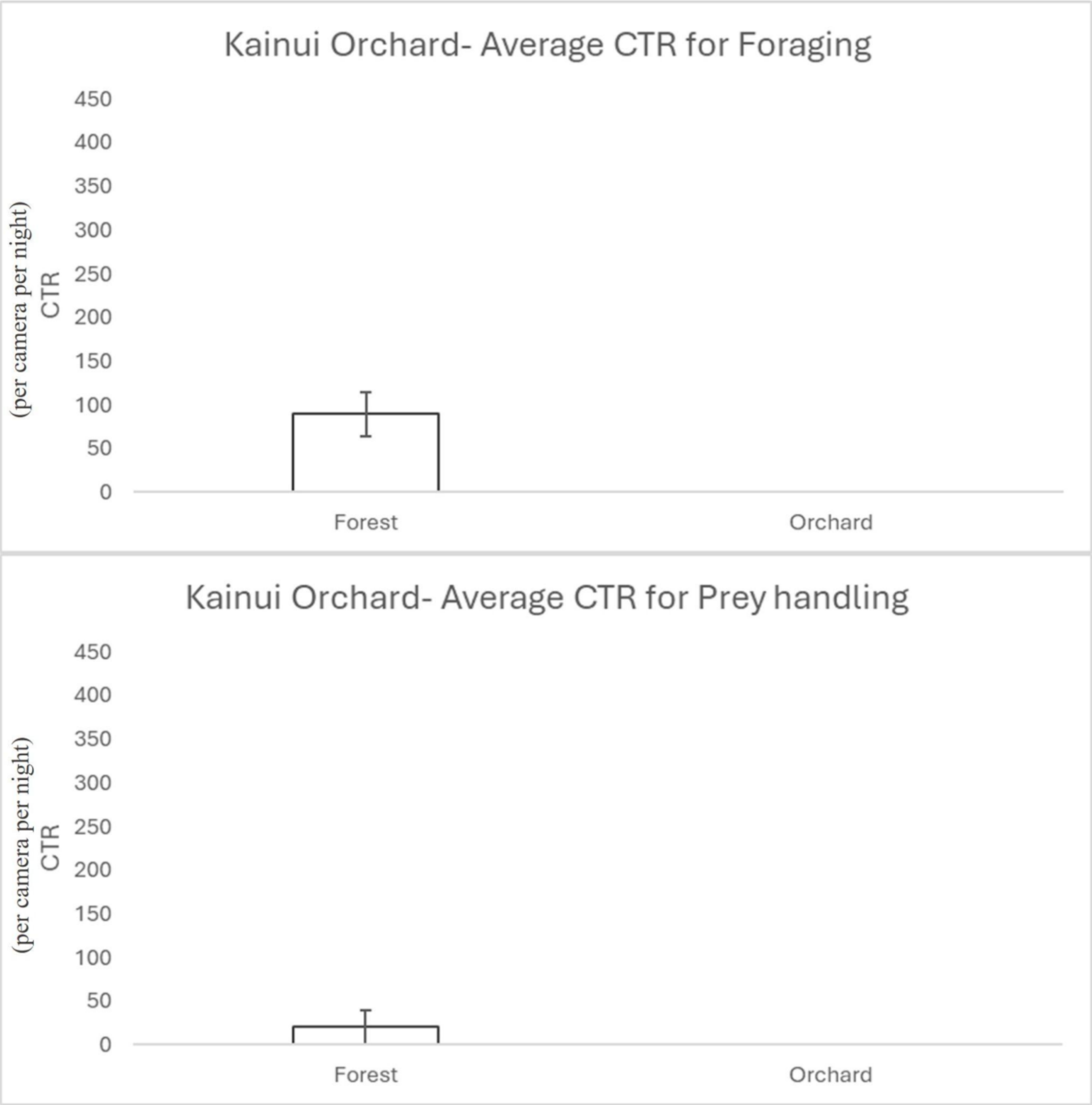


Figure 3.16 Kiwi average camera capture rate for foraging vs. prey handling- Kainui Orchard

3.3.2 Acoustic recorders overall results

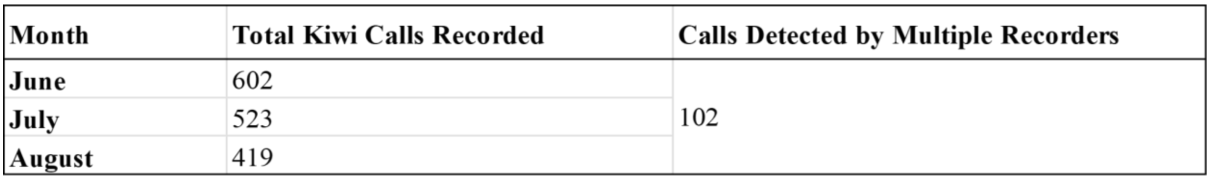
Acoustic recorders were placed at Craigmore to monitor the call activity of the North Island brown kiwi. During the study period, a total of 1,073 calls were recorded, with the frequency of calls varying between months. Among them, the highest number of calls was in June (602 calls), followed by July (523 calls), and the lowest number of calls was in August (419 calls).

Of all the recorded calls, 102 calls were detected by multiple recorders simultaneously, indicating overlapping detection areas. Calls were classified into different types based on their acoustic structure. Type A was the most frequently recorded type in duets, occurring in 70% of duet instances, and usually following the female's call. The D type was also common in duet calls, accounting for 70%, and female calls were often followed by or overlapped with this type.

For single-calling male kiwis, types B, C, and D were the most common, accounting for 84% of all single-calling male kiwis. These calls also had a longer total call duration compared to other types of calls. Type F is the least documented call pattern and has been detected in both duets and single male calls.

These results provide an overview of kiwi call activity, capturing variation in call frequency and call type distribution among study sites (Table 3.6).

Table 3.6. Overall acoustic recorders result by months



Month	Total Kiwi Calls Recorded	Calls Detected by Multiple Recorders
June	602	102
July	523	
August	419	

3.3.2.1 Location of North Island Brown Kiwi Calls

Figure 3.17 shows the distribution of duet calls and single calls detected by more than one recorder kiwi calls recorded within the study site. A total of 102 call locations are shown. The locations on the map show that brown kiwi calling activity is widespread in orchards and surrounding bush areas. Kiwi calls were concentrated in specific areas within the study site, with higher densities in the central and northern parts of the mapped area. Fewer calls were recorded in the southern part of the orchard and the surrounding areas. The mapped data also showed changes in the location of male and female calls, with male calls occurring more clustered. The distribution of calls shows a pronounced density near the bush within the study site. The spatial arrangement of calls indicated that kiwi vocal activity was not evenly distributed across the study site.

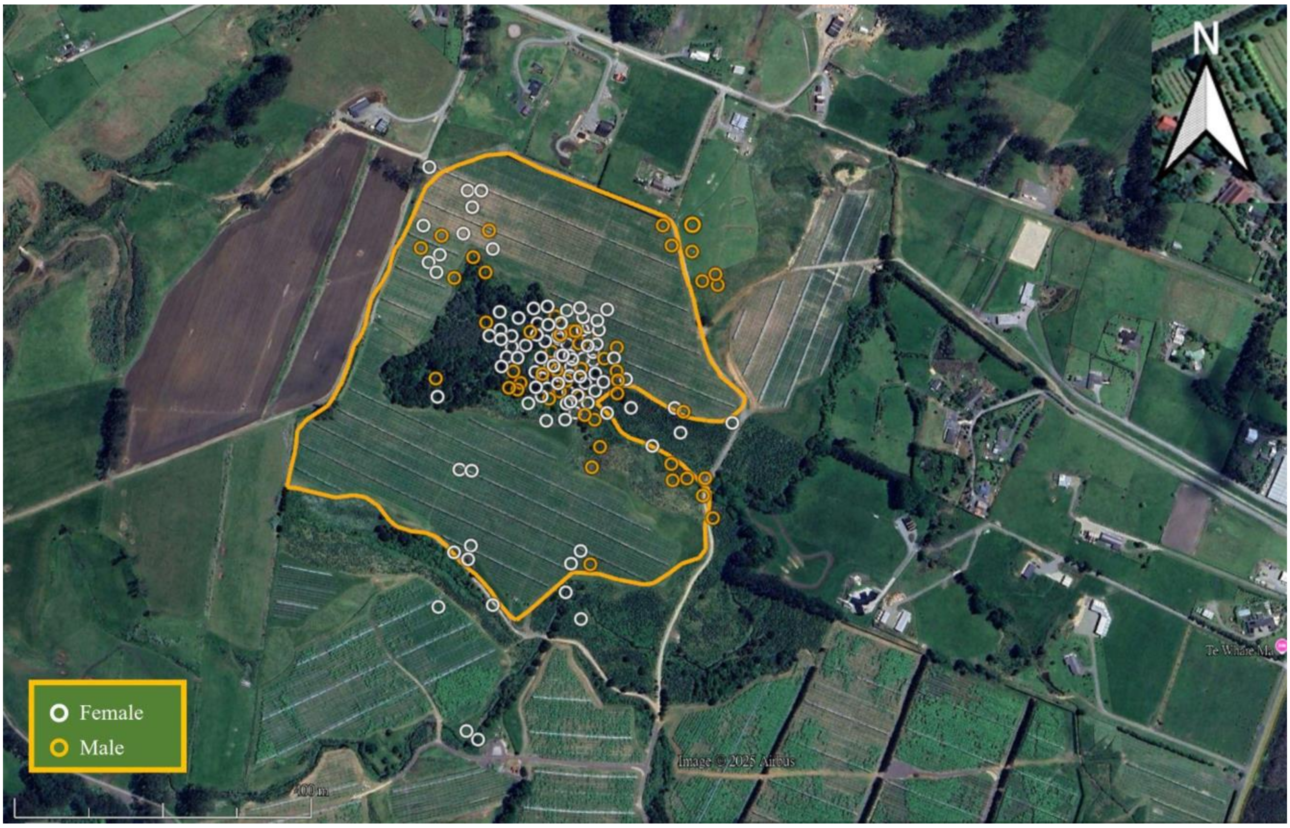


Figure 3.17 Recorded kiwi call location & sex

3.3.2.2 Estimation of the Population Size

Figure 3.18 presents the estimated locations of the North Island brown kiwi based on AR4 recorder detections. Three distinct kiwi detections were identified within the study area.

- **Single Kiwi A (Yellow triangle):** A single male was detected within the overlapping blue and green recorder ranges.
- **Pair Kiwi B (White triangle):** A pair was recorded with male and female calls detected within 10 minutes of each other near Kiwi A's location on June 13th and 16th.
- **Pair Kiwi C (White triangle):** Another pair was recorded on June 18th, with two calls detected within 10 minutes in the overlapping red and brown recorder ranges.

Based on the simultaneous calling events and detections within 10-minute intervals, the estimated minimum number of individual kiwi within the study area was four. The presence of at least two kiwi pairs suggests a minimum of four individual birds recorded, with Kiwi A potentially being the male from Pair C, as indicated by overlapping detection ranges. In addition to call-based estimation, a Spatial Capture-Recapture (SCR) model was applied to estimate population density within the study area. The results from the SCR model provide a density-based estimation, which will be presented in the following subsections.

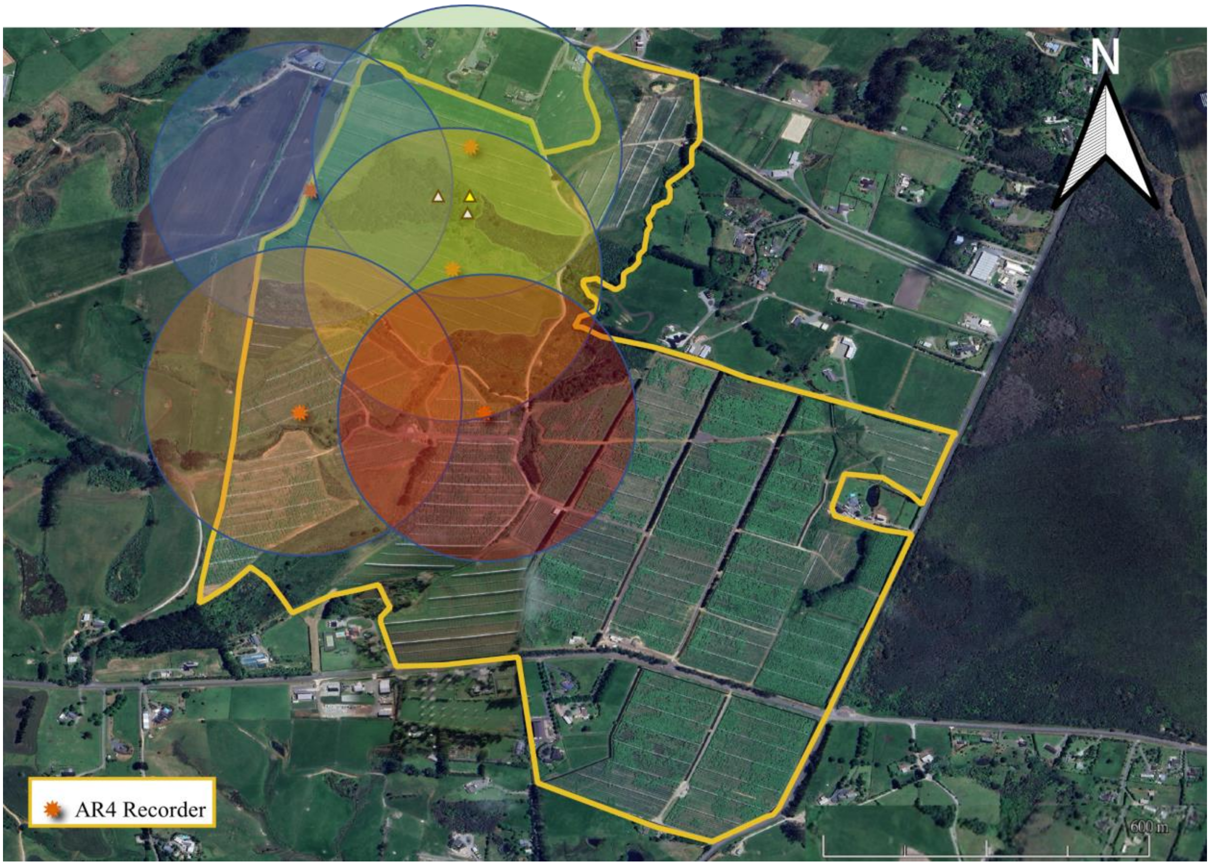


Figure 3.18 Recorded kiwi individual estimate location

3.3.2.2.1 SCR model Result

A spatial capture–recapture (SCR) model was used to estimate population density of the North Island brown kiwi within the study area. Model parameters are from detection data and provide an estimate of population size (Juodakis et al., 2021).

The estimated baseline detection probability ($g0$) is 0.9, and the spatial scale parameter (σ) is 250 m. The estimated population density is 0.01 individuals per hectare. Based on these estimates, the total number of kiwi in the survey area was determined to be approximately one. The estimated detection function (Figure 3.19) illustrates the probability of detecting a kiwi at different distances from the acoustic recorder. The chance of detection is highest at short range and decreases with distance, dropping below 0.25 at distances over 400 meters. This pattern suggests that kiwi were most likely to be detected close to the recorder and were less frequently found at greater distances. These results provide estimates of kiwi density within the study area, allowing for further analysis of their distribution and habitat use.

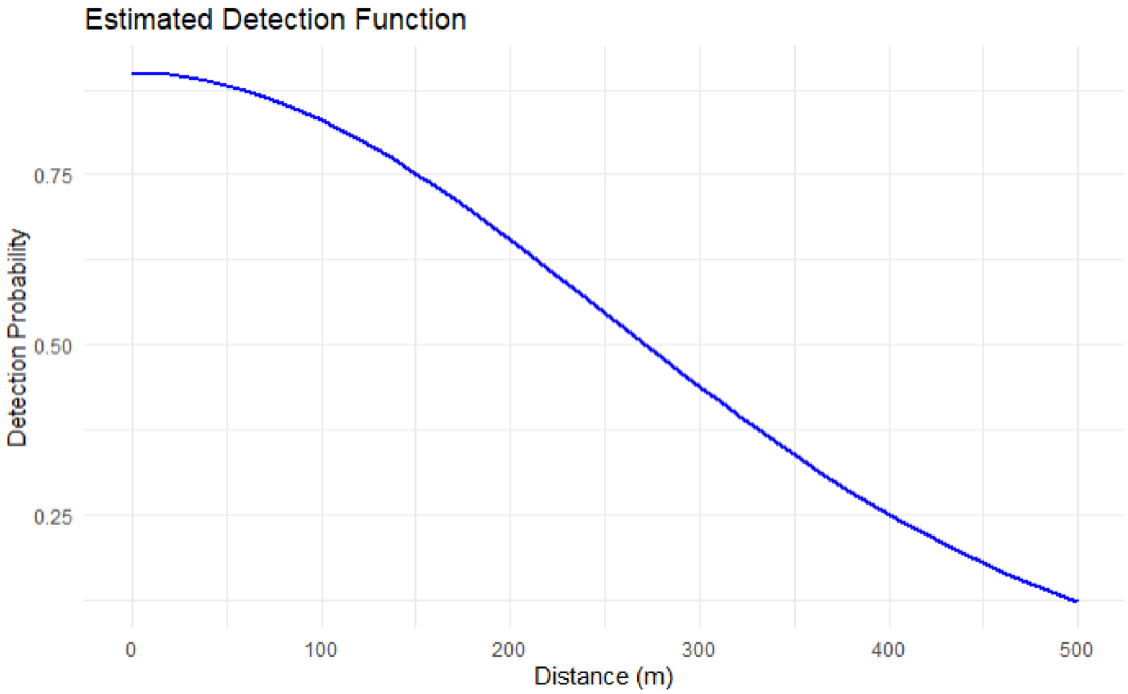


Figure 3.19 Estimated detection function

3.3.3 Comparison of Activity Patterns between Camera Traps andAcoustic Recorders

Kiwi activity recorded by AR4 recorders was highest between the 2nd and 5th hours after sunset, with peaks at the 2nd hour (12 calls) and 5th hour (15 calls). The AR4 recorders consistently detected higher numbers of kiwi calls across all hours compared to images by the camera traps. To ensure comparability, Figure 3.20 includes only data from months and sites where recorder and camera trap deployment overlapped. Camera trap results were limited to the period during which AR4 recorders were active.

Camera traps recorded lower kiwi activity overall, with the highest number of videos observed during the 9th hour after sunset (8 videos). From the 6th to 10th hours after sunset, both recording methods captured similar trends, with moderate activity levels recorded. After the 10th hours, kiwi detections declined for both AR4 recorders and camera traps, with minimal activity recorded beyond the 12th hour after sunset. These results indicate differences in kiwi activity detection patterns between AR4 recorders and camera traps across the recorded time intervals (Figure 3.20).

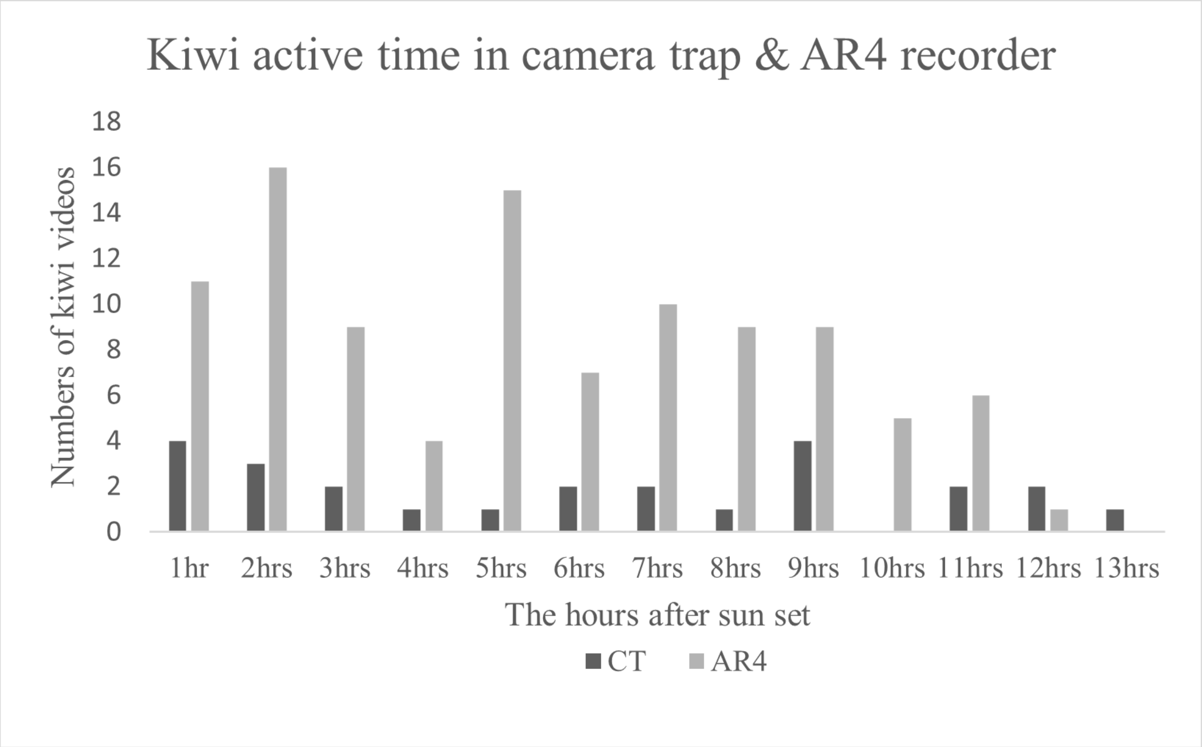


Figure 3.20. The bar chart displays the number of kiwi videos recorded by camera traps (CT) and AR4 recorders (AR4) across different hours after sunset.

3.4 Discussion

3.4.1 Camera traps

The camera trap data collected across the four study sites provided valuable insights into kiwi activity, as well as the broader ecological context of these environments. The results indicated variations in the number of detected kiwi videos among sites, suggesting differences in habitat suitability and potential kiwi population densities. Puriri Park recorded the highest number of confirmed kiwi videos, followed by

Craigmore, The Landing, and Kainui Orchard. This pattern may be attributed to variations in vegetation cover, food availability, and habitat connectivity, which influence kiwi movement and activity levels. The lower number of kiwi detections at Kainui Orchard may indicate either a lower local population density or limited accessibility to preferred foraging grounds.

The camera trap results suggest that the North Island brown kiwi tend to be more active in bush-covered areas at most study sites, except in Puriri Park, where kiwi activity was higher in orchard areas. This variation highlights the influence of specific habitat characteristics on kiwi activity patterns in modified environments. Puriri Park differs from other sites in that its orchard areas may provide a more suitable microhabitat. This may be due to factors such as greater vegetation complexity in the nearby native bush, reduced human disturbance or differences in soil composition that affect prey availability. Additionally, the dense canopy of kiwifruit vines in the orchards, which is not observed at other study sites, may also contribute to increased kiwi activity by providing shelter.

The observed differences underscore the importance of canopy cover and other habitat features in shaping kiwi behaviour. Sites with dense vegetation and natural bush cover likely offer more favourable conditions by providing shelter from predators and maintaining higher humidity levels, which may enhance invertebrate abundance. In contrast, more open areas, particularly those with reduced canopy cover, may be less suitable due to increased exposure to predators and environmental disturbances, such as temperature fluctuations and soil desiccation. Further research is needed to identify the specific habitat attributes that contribute to the higher kiwi activity observed in orchard areas at Puriri Park, as well as to assess how these factors may influence kiwi behaviour across different modified landscapes.

The proportion of false triggers varied significantly among sites, with The Landing recording the highest number of false triggers. This suggests that environmental factors, such as wind movement or non-target animal activity, have influenced camera activations. The presence of numerous false triggers highlights a limitation of camera traps, as they may record unnecessary footage, making data processing time-consuming. However, despite this limitation, camera traps remain an effective non-invasive tool for monitoring kiwi presence, behaviour, and activity patterns.

The presence of introduced mammalian predators such as cats, stoats, and possums across multiple sites raises concerns about the potential impact on kiwi populations. Craigmore, for example, recorded stoats, a known predator of kiwi chicks, which could pose a significant risk to local populations. The high number of introduced mammals detected across all sites further highlights the ongoing challenges in managing invasive species in these modified landscapes. Conservation efforts focusing on enhancing predator control may be necessary to further improve the survival rates of kiwi in these environments. While predator control is already implemented in all of the study sites increasing the intensity or coverage of these efforts could be beneficial.

The camera trap data also showed a variety of native and introduced bird species. The frequent presence of species such as blackbirds, magpies, and pheasants at multiple sites suggests that kiwi share these habitats with a diverse avian community. The detection of birds of prey, including the New Zealand falcon, suggests that some sites may offer ecological benefits by supporting native predatory species that contribute to pest control.

While camera traps successfully captured kiwi activity, their effectiveness in estimating population densities remains limited (Palencia et al., 2021; Li et al., 2023). The data only provides information on the presence and frequency of detections but does not account for repeated sightings of the same individuals. Future studies could improve accuracy by integrating camera traps with other monitoring techniques, such as radio telemetry or genetic analysis, to obtain more precise population estimates.

Overall, the camera trap findings highlight the importance of habitat management, predator control management, and long-term monitoring kiwi populations in modified landscapes. Understanding the spatial distribution and behaviour of kiwi in these environments will be crucial for conservation planning and ensuring the long-term viability of this species.

3.4.1.1 North Island Brown Kiwi capture rates in videos by study site and season

The results indicate significant variation in the North Island brown kiwi capture rates across different orchard locations and seasons, reflecting both environmental influences and potential behavioural patterns of the species. Among the study sites, Puriri Park consistently recorded the highest overall capture rates, particularly in March (27.42 per camera per night) and August (25.81 per camera per night), suggesting periods of increased kiwi activity. This trend may correspond with seasonal factors such as breeding behaviour or changes in food availability. In contrast, Kainui Orchard exhibited the lowest capture rates, with the highest rate being only 8.00 (per camera per night) in June, indicating limited kiwi presence or lower detectability at this site.

Craigmore showed relatively stable but moderate capture rates throughout the months, with a peak in February (5.56 per camera per night). The Landing, however, demonstrated a gradual increase from March (5.53 per camera per night) to May (25.93

per camera per night), before declining in the later months. This pattern suggests that kiwi activity at The Landing may be influenced by environmental factors such as temperature, resource availability, or disturbance levels.

The environment in vineyards and kiwifruit orchards may vary significantly, and these differences could influence the activity of the North Island brown kiwi. Factors such as canopy cover, soil moisture, habitat characteristics, surrounding native bush, and horticultural management practices are likely key elements affecting kiwi behaviour in these settings (Taborsky& Taborsky, 1995). Sites with dense canopy cover, such as Puriri Park, exhibited higher kiwi activity compared to areas with limited canopy cover, such as Craigmore. Canopy cover provides essential protection from predators and can create favourable microhabitats similar to the species' natural forest environment. In contrast, open environments such as vineyards, which generally lack sufficient overhead cover, may be less suitable due to increased exposure to predators and weather conditions.

Soil moisture and organic matter also play a role in influencing kiwi activity, particularly through their impact on food availability. Higher soil moisture supports a greater abundance of invertebrates, which are a primary food source for kiwi. The study sites with higher soil moisture content, such as Puriri Park and Kainui Orchard, exhibited greater kiwi activity, while Craigmore, characterised by drier soils, showed lower capture rates. This suggests that soil conditions contribute to habitat suitability for kiwi in modified landscapes.

The connectivity of orchards to native bush also played a role in shaping kiwi activity. Sites with direct access to surrounding bush areas, such as The Landing and Puriri Park, recorded higher kiwi capture rates. However, this situation was not consistent across all sites. Kainui Orchard, despite having a substantial bush area nearby, especially across the road, did not see the same kiwi activity level. This difference may be due to habitat fragmentation caused by roads and windbreaks, which could be a barrier to their movement and limit kiwi access to these suitable bush areas. In contrast, Craigmore, which is more isolated from large native bush areas, exhibited reduced kiwi activity. The presence of native bush provides important resources, including food, roosting and nesting sites, and facilitates movement between different habitat patches. Improving habitat connectivity by maintaining or restoring native vegetation within horticultural landscapes could enhance the suitability of these environments for kiwi.

The distinction between orchard and bush habitats was evident in the results, with capture rates generally being higher in bush areas compared to orchards. At The Landing, the bush area recorded a significantly higher capture rate (43.72 per camera per night) than the orchard area (1.66 per camera per night). Similarly, Craigmore’s bush area showed a higher rate (9.03 per camera per night) than its orchard area (0.40 per camera per night). This supports the expectation that kiwi prefer native bush habitats for foraging and shelter, despite their occasional presence in orchards. Interestingly, Puriri Park was an exception, where the capture rate in the orchard area (16.64 per camera per night) was higher than in the bush area (6.87 per camera per night). This may indicate site-specific factors, such as habitat quality or availability of food resources, encouraging kiwi activity in the orchard.

Seasonal fluctuations in capture rates suggest that kiwi activity patterns are not uniform throughout the year. The peak activity in March and August at Puriri Park and the gradual rise from March to May at The Landing indicate possible seasonal drivers, including changes in temperature, breeding cycles, or prey abundance. The decline in capture rates after May at multiple sites may reflect seasonal movement or reduced detectability due to environmental conditions such as weather changes.

The absence of recorded kiwi activity in certain months and sites suggests that factors such as habitat suitability, predation risks, or human disturbance may influence their distribution. The notably low capture rates at Kainui Orchard, where kiwi detections were only in the bush area, further emphasise the species' preference for less disturbed habitats. This pattern may be influenced by the presence of windbreaks, which likely act as barriers preventing kiwi from accessing the nearby bush area. This aligns with a previous study (Taborsky et al., 1995) indicating that kiwi tend to avoid open, modified environments unless sufficient cover or food resources are present.

Overall, these findings highlight the importance of maintaining and restoring native bush areas within orchard landscapes to support kiwi populations. The presence of kiwi in orchard areas, particularly at Puriri Park, suggests potential adaptability, but further investigation is needed to determine whether this reflects opportunistic foraging behaviour or a broader habitat shift. Future studies should explore the role of specific environmental factors, such as microhabitat structure and food availability, in influencing kiwi distribution across modified landscapes.

3.4.1.2 Habitat Utilisation Using Heatmaps from Camera Traps

Heat maps generated from camera traps provide valuable insights into the movement and habitat use of the North Island brown kiwi across the study sites. These maps highlight significant spatial variation in kiwi activity, with clear differences observed between bushland and orchard areas. In general, greater capture rates were concentrated in areas dominated by forest, while lower capture rates were recorded in orchard areas. This aligns with previous research suggesting that kiwi prefer dense vegetation for foraging and shelter (Taborsky& Taborsky,1995; Jamieson et al, 2016), likely due to the availability of invertebrate prey and protection from predators.

At The Landing, the highest capture rates were recorded in bush areas near the main road, specifically at CT2, CT7, and CT10. This suggests that these areas provide favourable conditions for kiwi activity, likely due to suitable foraging grounds and minimal human disturbance. Similarly, at Craigmore, CT11 and CT6 — both located in bush— showed the highest capture rates, reinforcing the importance of bushland areas for kiwi survival.

In Puriri Park, the highest capture rate was recorded at CT3, an orchard site, suggesting that kiwi may exploit certain orchard areas under specific conditions. This could indicate that some orchards provide sufficient food resources or cover to make them viable secondary habitats. However, Kainui Orchard displayed a different trend, with the highest capture rate at CT5, a site within the bush area, reflecting a stronger preference for native habitats over modified landscapes. This pattern may be influenced by factors limiting kiwi movement into the orchard. Windbreaks and the road likely act as barriers, restricting access and concentrating kiwi activity in the bush. These structural and environmental constraints should be considered when interpreting the capture rates at Kainui Orchard, as they may not fully reflect habitat preferences.

These results suggest that while kiwi primarily utilise bush areas, their occasional presence in orchards indicates a level of habitat adaptability. Despite this, the overall lower capture rates in most orchard areas imply that these environments may not provide optimal conditions for kiwi activity, potentially due to prey decline, human activity, or exposure to agricultural chemicals. The presence of kiwi in certain orchard sites, particularly in Puriri Park, raises important questions about whether modified landscapes could support kiwi populations under targeted management strategies.

Kiwi are more likely to enter orchard areas when they are linked to native bush, as these connections facilitate movement between different environments. In contrast, isolated orchards and vineyards that lack such connectivity are less accessible and less frequently used by kiwi. Improving habitat connectivity through green corridors, native hedgerows, or preserving patches of native vegetation within and around horticultural areas could enhance kiwi movement and increase their use of modified landscapes.

The habitat structure at each site contributed to variations in kiwi activity levels. At The Landing, extensive adjacent native bush provided an effective corridor for kiwi to access orchard areas. The infrequent mowing of grass resulted in substantial ground cover, offering concealment and enhancing the security of foraging spaces.

Puriri Park, with its dense undergrowth and mixed vegetation, showed the highest kiwi activity. The presence of diverse plant species likely contributed to increased invertebrate abundance, providing a reliable food source for kiwi. By contrast, Craigmore featured open habitats with limited ground vegetation, creating a less secure environment and potentially deterring kiwi from using these areas extensively.

The complexity of vegetation is an important factor in sustaining kiwi populations. Areas with richer plant diversity and dense understory vegetation tend to support greater invertebrate abundance, enhancing foraging opportunities (Taborsky et al., 1995; Cunningham & Castro, 2011). Kiwi primarily feed on soil invertebrates and prefer moist habitats with dense understory vegetation, which supports abundant prey. Research indicates that kiwi utilise both native forests and pastures, spending about 75% of their nocturnal activity foraging. However, prey capture rates are higher in pastures than in forests, suggesting that habitat type and vegetation complexity influence foraging success. Encouraging native vegetation in orchards and maintaining understory complexity could improve habitat suitability for kiwi in modified landscapes.

The heatmap analysis highlights the importance of native bush for kiwi survival, with occasional use of orchard areas showing some habitat adaptability. However, lower capture rates in orchards indicate these environments may not provide optimal conditions.

Future studies should explore the specific factors that influence kiwi activity in modified landscapes, particularly food availability, predation risks, and human disturbance. Integrating additional environmental variables, such as soil composition and invertebrate abundance, into future analyses could provide a more comprehensive understanding of kiwi habitat preferences.

The findings emphasise the importance of habitat enhancements, such as increasing canopy cover and improving connectivity to native bush, in supporting kiwi populations. By promoting sustainable habitat management, conservation efforts can create landscapes that balance agricultural productivity with biodiversity conservation, ensuring the continued survival of the North Island brown kiwi in modified environments.

3.4.1.3 Puriri Park and the Canopy Cover Hypothesis

Kiwi activity was highest in the orchard areas of Puriri Park, whereas this trend was not observed at other study sites. Dense canopy cover in orchards may contribute to this pattern by providing nice microhabitats, reducing predation risk and maintaining high humidity levels (Figure 3.21). Unlike other areas where kiwi is mostly found in bush areas. The relationship between canopy cover and kiwi activity was proven across sites. Areas with extensive canopy cover (such as Puriri Park) recorded more kiwi activity, while areas with limited canopy cover (such as Craigmore) recorded less kiwi activity. Dense canopy likely provides essential protection from predators and creates a microhabitat that closely resembles a natural forest environment (Colbourne & Kleinpaste, 1983). In contrast, more open environments, including vineyards, may increase kiwi exposure to predators and reduce available refuge (McLennan et al. 1996). Kiwifruit orchards provide moderate to dense canopy cover through vine structures and appear to be a compromise between natural bush and highly modified environments. Enhancing canopy cover by increasing vine density or incorporating native vegetation may improve habitat suitability for kiwi in orchards. However, further research is needed to assess whether similar conditions in other orchards get similar results and to determine the long-term viability of these environments as habitats for kiwi.

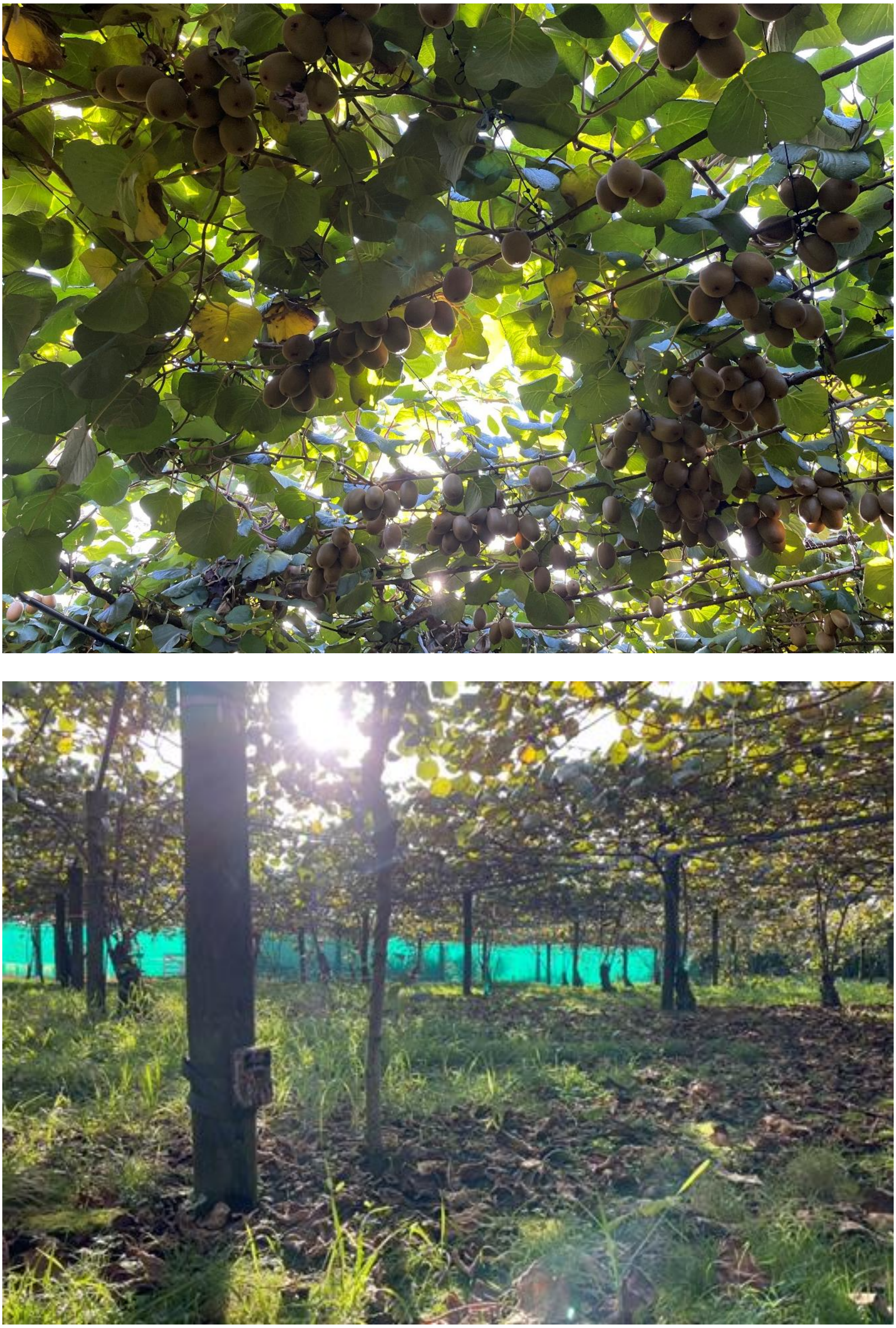


Figure 3.21. Puriri Park canopy cover in the kiwifruit orchard area

3.4.1.4 Pattern of North Island Brown Kiwi activity time at each study site

The movement patterns of the North Island brown kiwi varied significantly between study sites and habitat types. Overall, kiwi were more active in bush areas than in orchards, with consistently higher capture rates recorded in bush environments. This finding suggests that kiwi prefer dense vegetation, which likely provides better foraging opportunities and greater protection from predators.

The peak activity of kiwi varies depending on habitat type. In bush areas, the highest capture rates occurred around nine hours after sunset, while in orchards, peak activity was within the first hour. This suggests that kiwi in orchards may forage earlier, while those in bush environments remain active later in the night due to greater cover and security. Habitat structure appears to play a key role in shaping foraging behaviour. Across all sites, kiwi activity declines later in the night, indicating a concentration of foraging behaviour in the early evening to midnight hours before getting back to safer bush areas. This pattern is especially proven in orchard environments, where activity drops sharply after the initial peak. This situation showed how habitat structure influences behavioural adaptations (Cunningham& Castro, 2011).

Seasonal changes in kiwi activity were obvious across the study sites. Overall, capture rates were highest in summer, second highest in autumn, and lowest in winter. Increased summer activity may reflect increased prey availability and favourable foraging environmental conditions. In winter, their activity level decreases. Longer nights in winter may provide more opportunities to reach the food amount they need with less foraging effort (Cunningham& Castro, 2011). That means greater prey capture efficiency may reduce the need for long-term activity. These activity patterns show that kiwi adjust their behaviour in response to seasonal changes in food availability and environmental conditions.

In addition to habitat structure, microclimatic factors also played a role in influencing kiwi activity patterns. Sites with more stable microclimates - characterised by moderate temperatures and higher humidity - were more attractive to kiwi. These conditions closely resemble the natural forest environments that kiwi prefer, providing thermal comfort and reducing physiological stress from extreme temperatures. In contrast, areas with more open landscapes, such as vineyards or sparsely vegetated orchards, may be less suitable due to greater exposure to temperature fluctuations and drier conditions.

Human activity also had an impact on kiwi movement patterns. Vehicle movement, people walking in the orchard areas, or agricultural activities may deter kiwi from using certain areas, particularly in orchards where human presence is more pronounced.

The differences in activity patterns observed across habitats and seasons provide valuable insights into how kiwi adapt to different environments. The preference for bush areas suggests that maintaining and restoring native vegetation is crucial for supporting kiwi populations. However, the occasional presence of kiwi in orchards, particularly in sites like Puriri Park, raises important questions about the potential for modified landscapes to serve as secondary habitats.

A key factor influencing the presence of kiwi in an orchard area is the relative size of the orchard relative to the extent of nearby native bush. Puriri Park is the smallest site but is surrounded by large areas of native bush, which may enhance its suitability for kiwi. In contrast, The Landing has smaller patches of native bush and recorded lower kiwi activity. This suggests that the overall connectivity and extent of native bush around sites may play a greater role in determining kiwi presence. Isolated patches of native bush within orchards may have less influence in sustaining a stable kiwi population. Furthermore, the effects of canopy cover that have been observed in Puriri Park support the idea that structural complexity and vegetation density may create more favourable conditions for kiwi in altered environments. This suggests that enhancing canopy cover and maintaining vegetation complexity could be important factors in promoting kiwi activity in modified landscapes.

Future research should investigate whether specific orchard management practices, such as reducing pesticide use, maintaining ground cover, or retaining patches of natural bush, can improve kiwi habitat suitability. Additionally, understanding the impact of human activities and predator presence on kiwi movement patterns will be essential for developing conservation strategies that enhance kiwi survival in modified environments.

Overall, these findings highlight the complex interactions between habitat structure, seasonal conditions, and external disturbances in shaping kiwi activity patterns. By addressing these factors through targeted habitat management and conservation efforts, it may be possible to create agricultural landscapes that better support kiwi populations while maintaining productive orchards.

3.4.1.5 North Island Brown 6iwi Behaviour Type Composition

The results reveal notable variations in the behavioural composition of the North Island brown kiwi across different study sites and habitat types. Walking was the most frequently observed behaviour overall, followed by Foraging. This aligns with the expected movement patterns of kiwi, as they are nocturnal, ground-dwelling birds that forage extensively during their active hours (Cunningham& Castro, 2011; Le Duc et al., 2015). The low occurrence of ‘can't tell’ behaviours suggests that most video footage provided clear visibility of kiwi activities, enhancing the reliability of the observations.

A key distinction was observed between forest and orchard environments. In forest areas, ‘Walking’ and Foraging’ were the dominant behaviours, with ‘Social’ interactions being the least common. This suggests that kiwi spend most of their time actively searching for food and moving within their natural bush habitats. In contrast, ‘Foraging’ was the most frequently recorded behaviour in orchards, followed by ‘Walking’. The reduced occurrence of ‘Social’ and ‘Comfort’ behaviours in orchards suggests that these environments may not provide the same level of security or familiarity as bush habitats, possibly leading to more cautious behaviour.

When analysing site-specific patterns, The Landing showed a high frequency of ‘Walking’ and ‘Foraging’ in bush areas, with minimal ‘Social’ interactions. Craigmore had a similar trend, with ‘Foraging’ being the most common behaviour across both forest and orchard areas, followed by ‘Prey handling’. This indicates that Craigmore may provide a reliable food source for kiwi, requiring more ‘Prey-handling’ behaviours compared to other sites. Puriri Park was unique in that walking was more frequent than foraging in both forest and orchard areas, possibly due to differences in habitat structure or food availability. In contrast, at Kainui Orchard, ‘Foraging’ was the most recorded behaviour, supporting the idea that kiwi in this site were actively searching for food rather than moving extensively. Interestingly, the results showed that ‘Foraging’ was generally more frequent in forested areas across most sites, except in Puriri Park, where kiwi exhibited more foraging activity in orchards. This could indicate a difference in food availability or a shift in behaviour due to environmental factors. Puriri Park orchard may provide easily accessible food sources, making it an attractive foraging location.

Overall, the behavioural composition of kiwi across different environments suggests that while they rely on ‘Walking’ and ‘Foraging’ as primary activities, habitat characteristics play a role in influencing behaviour patterns. The higher prevalence of foraging in some orchard environments may indicate behavioural adaptation in modified habitats, while the low frequency of social behaviours suggests that kiwi prefer solitary activities, consistent with their known ecological traits. Future research could explore whether these behavioural differences influence kiwi survival and adaptation in modified habitats.

3.4.1.6 Foraging Use of North Island Brown Kiwi in Horticultural Settings

The results demonstrated significant differences in the foraging activity of the North Island brown kiwi between bush and orchard areas. Across the study sites, kiwi consistently exhibited a preference for foraging in forest environments rather than orchards. This pattern suggests that native forests provide more suitable conditions for foraging, likely due to higher prey availability, greater soil moisture, and better protective ground cover. Camera trap capture rates (CTR) for foraging behaviour were slightly higher in bush areas, reinforcing the importance of these habitats in supporting kiwi populations.

Among the study sites, The Landing and Craigmore exhibited a strong preference for foraging in forested areas, with significantly higher CTR compared to orchard environments. This aligns with expectations, as native forests typically support a more diverse and abundant invertebrate community - an essential food source for kiwi. Additionally, prey-handling behaviours, such as probing and food manipulation, were more frequently recorded in forest environments, further suggesting that these areas provide more reliable foraging opportunities.

However, Puriri Park deviated from this general trend. In contrast to other study sites, kiwi at Puriri Park were recorded ‘Foraging’ and ‘Prey handling’ more frequently in orchard areas than in the surrounding forest. This unusual pattern may be attributed to specific environmental conditions within the orchard, such as higher soil moisture, richer organic content, or an abundance of invertebrate prey. Alternatively, it is possible that the forested areas at Puriri Park offered fewer food resources, prompting kiwi to seek alternative foraging grounds within the orchard. These findings suggest that, under certain conditions, modified landscapes like orchards may provide viable foraging habitats for kiwi.

At Kainui Orchard, overall foraging activity was the lowest among all study sites, with no prey-handling behaviours recorded in orchard areas. This may be due to intensive horticultural management practices, which can reduce invertebrate diversity and limit food availability for kiwi.

The observed differences in foraging behaviour between forested and orchard environments may also be influenced by canopy cover. In general, kiwi were more active in areas with greater canopy coverage, as seen in Puriri Park and certain sections of The Landing. The denser canopy in some orchards, particularly those with mature vine structures, may offer greater protection from predators, reducing the risks associated with foraging in open landscapes. These findings align with studies on other ground-dwelling birds, which have shown that canopy cover plays a critical role in influencing habitat use and foraging behaviour (Wilson et al., 2005). In contrast, vineyards and sparsely vegetated orchard areas may provide insufficient shelter, making them less suitable for kiwi foraging (McLennan et al., 1996; Taborsky & Taborsky, 1995).

Soil conditions also appeared to play a crucial role in determining kiwi foraging activity. The study sites showed clear variations in soil moisture and organic matter content, which were correlated to kiwi foraging behaviour. While no measured data on soil moisture were collected, these observations are based on direct personal observations made during fieldwork. Sites with higher soil moisture, such as Puriri Park and Kainui Orchard, exhibited greater kiwi activity compared to drier locations like Craigmore. Moist soil supports a richer abundance of invertebrates, including earthworms, beetles, and other insects that form a significant part of the kiwi’s diet (Craig, 2011). Additionally, soil with high organic content provides a better structure and supports a diverse community of soil organisms (Bell et al, 2003), creating a more reliable food source for kiwi.

Conversely, Craigmore’s drier soils likely contributed to lower foraging activity. Harder, drier soils reduce the availability of prey items and increase the physical effort required for kiwi to probe for food. This may explain why kiwi at Craigmore exhibited limited foraging behaviours despite the presence of suitable habitat. These findings highlight the importance of soil health in supporting kiwi populations and suggest that conservation efforts in horticultural landscapes should prioritise maintaining soil moisture and organic matter to enhance food availability for kiwi.

The findings of this study indicate that while kiwi strongly prefer forested habitats for foraging, certain orchard environments, such as Puriri Park, may also serve as important supplementary foraging grounds under the right conditions. This highlights the potential for modified landscapes to support kiwi populations if managed appropriately.

Future research should focus on identifying the specific environmental factors that influence kiwi foraging behaviour in orchard settings. Studies on invertebrate abundance, soil composition, and canopy structure could help determine what conditions make certain orchards more suitable for kiwi activity. Additionally, exploring the impacts of different orchard management practices, such as pesticide use and vegetation cover retention, could provide valuable insights into how agricultural landscapes can be modified to better support kiwi conservation.

Overall, these findings highlight the importance of maintaining and restoring native bush near horticultural areas to ensure the long-term survival of kiwi populations. However, the case of Puriri Park suggests that, with proper management, some orchard environments may also provide valuable foraging opportunities for kiwi. Understanding how kiwi interact with different landscape features will be essential for developing conservation strategies that balance agricultural productivity with biodiversity protection.

3.4.2 Acoustic Recorders General Results

These acoustic recordings provide valuable insights into kiwi vocal activity at the study site, revealing patterns in vocal behaviour and potential factors influencing these trends. A total of 1,073 recorded calls indicated that kiwi was actively vocalising across the study period, but with clear fluctuations in call frequency. June recorded the highest number of calls (602 per month), followed by July (523 per month), and August (419 per month). The decline in call frequency over these months may be linked to seasonal changes in kiwi behaviour. June and July mark the peak of the kiwi breeding season, during which males call more frequently to establish territories and attract mates (Miles et al., 1997; Colbourne& Digby, 2016). As the season progresses into August, calling activity may decrease as kiwi shift their focus to nesting and incubation, reducing the need for vocal communication. This pattern shows that kiwi calling intensity peaks during the early breeding period before tapering off later in the season.

The results also indicate that different male kiwi calling patterns may be associated with duet or single calls. Type A was found in 70% of duets and typically followed the female call immediately. Similarly, Type D was also common in duets (70%), with female calls often following immediately or overlapping. This suggests that Type A and Type D may facilitate vocal coordination between paired kiwi, indicating a close vocal relationship. For single-calling males, Types B, C, and D were the most frequent, comprising 84% of all single male calls. These calls also had a longer total duration compared to other call types, suggesting that males may use these patterns for extended vocal displays. In contrast, Type F was the least common and recorded in both duet and single male calls. The rarity of Type F makes it difficult to determine its function, and further data collection is necessary to understand its role.

Given that this study was conducted at a single study site with a limited sample size, the results should be interpreted with caution. The observed frequencies of calling patterns may not fully represent the wider kiwi population. Further research using larger datasets across multiple study sites is necessary to confirm these findings and explore whether environmental or individual factors influence call type distribution. Future research could also explore the relationship between kiwi call frequency and environmental variables, such as temperature, moon phase, or predator presence, to better understand the factors influencing vocal behaviour. Additionally, integrating acoustic recordings with camera trap data could provide further insights into how kiwi movement and calling behaviour align (Grant, 2012; Fan, 2023).

Overall, these findings emphasise the importance of acoustic monitoring as a tool for assessing kiwi activity and habitat use. The observed seasonal variations, calling pattern differences, and overlapping detections highlight the need for targeted conservation strategies that consider both behavioural patterns and environmental influences on kiwi vocal activity.

3.4.2.1 Location of Recorded North Island Brown Kiwi Calls

The distribution of kiwi calls within the study sites revealed clear spatial patterns of kiwi vocal activity. The bird calls were concentrated in specific areas, particularly in the central and northern parts of the site, suggesting that these areas may have provided more suitable habitat for the kiwis or served as key communication areas. The lower call density in orchards south of the area shown in the map and surrounding areas suggests that these areas may be less used by kiwi, which may be due to environmental factors such as vegetation cover, food supply, or human activity disturbance.

The observed differences in the location of male and female song calls provided further insight into kiwi behaviour. In some groups, males called more frequently, possibly indicating territoriality or more vocal activity during the breeding season. Hearing female calls in overlapping areas indicates potential breeding sites or shared feeding grounds. This spatial distribution is consistent with what is known about kiwi behaviour: males use vocalisations to establish territories and attract mates (New Zealand Birds Online, n.d.), while females are less vocal but still communicate.

The proximity of the calls to bush areas suggests these sites play a crucial role in kiwi migration and social interactions. The forest environment may provide shelter and protection compared to an open orchard area, thus encouraging more vocal activity. The structural layout of orchards may also affect the distribution of calls, as kiwis may prefer natural cover when vocalising.

Although the AR4 recorders provided reliable call location data, the study was limited by the exclusion of calls with insufficient detection points. This means that some areas with fewer recorders may have undetected acoustic activity, leading to an underestimation of kiwi numbers in those areas. Additionally, factors such as background noise, wind, and recorder location may affect the accuracy of call detection (Apol et al., 2020; Digby et al., 2013).

Overall, the spatial distribution of kiwi calls highlighted key habitat preferences and potential social dynamics within the study sites. Further research could explore seasonal variations in calling patterns, the impact of environmental conditions on vocal activity, and the role of human disturbance in shaping kiwi communication behaviour.

3.4.2.2 Estimate of North Island Brown Kiwi Population Size

The estimated kiwi locations provide insight into the spatial distribution and vocal behaviour of the North Island brown kiwi within the study area. The discovery of at least two pairs and one male kiwi suggests that the site hosts a small but active kiwi population. Overlapping recording ranges suggest that there may be movement between calling areas, particularly in the case of Kiwi A, which may be detected both as a single male and as a duet. This suggests that some individuals may migrate between different calling locations, either due to territorial movements or interactions with other kiwi.

Duets recorded over short periods further support the idea that these kiwi pairs engage in vocal communication, which could play a role in territory defence or mate establishment. The timing of detections also highlighted that kiwi calls are not randomly distributed across the landscape, but rather concentrated in a few areas, possibly influenced by habitat characteristics, social interactions or resource availability (Taborsky& Taborsky, 1995; Save the Kiwi, n.d.).

While the findings provide valuable insights, the exact abundance of kiwi in the region remains uncertain. The possibility that some test results represent the same individual making calls from different locations cannot be ruled out. Further monitoring using additional loggers or tracking methods could help clarify kiwi movement patterns and improve population estimates. Additionally, environmental factors such as vegetation density, background noise and recorder location may also affect detection rates, meaning some calls may go undetected. Understanding these limitations is important for interpreting the findings and improving future studies of kiwi distribution and vocal behaviour in modified landscapes.

3.4.2.3 Spatial Capture–Recapture Model Result

The spatial capture–recapture (SCR) model estimated the population density to be 0.01 individuals per hectare, with an estimated total number of individuals of 1 in the survey area. While the results provide initial insights into the kiwi population within the study site, the findings must be interpreted with caution due to the limitations of the dataset and methods (Gowan et al., 2021; Martin et al., 2024; Nolan et al., 2023).

A key limitation is the small sample size. During the study period, there were four nights with only one kiwi call recorded and one night with no kiwi call recorded at all. Such low detection rates suggest that the SCR model may have underestimated the density of kiwi due to insufficient data. Larger datasets and more frequent testing will improve the reliability of density estimates and provide a more accurate description of kiwi populations in the region.

The detection probability also plays a crucial role in the results, and the baseline detection probability (g_0) is estimated to be 0.9, and the spatial scale parameter (σ) is 250 meters. The detection function (Figure 3.19) illustrates how the probability of detecting a kiwi decreases with increasing distance from the logger, falling off sharply above 400 m. This suggests that, although kiwi calls can be more easily detected near the recorders, kiwi individuals at greater distances may not be detected. However, the key advantage of SCR methods is that they consider this variation in detection probability. This allows researchers to estimate and correct the probability of individuals going missing during a survey.

Another factor that could have affected the results is the small number of detections, which directly affects the accuracy of density estimation. The actual number of kiwi in the study area may be higher than estimated, but individuals outside the effective detection range were not included in the model. To address this issue, future studies could increase the number of recorded units or use alternative detection methods, such as camera traps, to supplement calling data and improve population estimates.

Additionally, habitat quality and site-specific conditions may also influence the presence of kiwi within the study area. Kiwi are known to prefer dense, low-disturbance environments, and changes in habitat structure, food availability, and predation risk may affect their distribution (Taborsky& Taborsky, 1995). Expanding the survey area and incorporating habitat assessments will provide a more complete understanding of kiwi density and movement patterns across different landscapes.

Despite these limitations, the SCR model remains a powerful tool for estimating kiwi population densities in modified environments. The findings highlight the importance of continued monitoring to refine density estimates and assess long-term trends in kiwi populations. Future studies should integrate multiple detection methods and optimise sampling designs to improve the accuracy and reliability of population estimates in similar study areas.

3.4.3 Comparison of Activity Patterns between Camera Traps and Acoustic Recorders

The differences in kiwi activity patterns recorded by AR4 recorders and camera traps suggest that each method has distinct advantages and limitations in detecting kiwi presence and behaviour. The AR4 recorders consistently detected higher kiwi activity across most hours, particularly between the 2nd and 5th hours after sunset, with notable peaks in the 2nd and 5th hours. This may indicate that kiwi are more vocally active during these early hours after emerging from their daytime shelters, possibly engaging in social communication before or during foraging.

In contrast, camera traps recorded lower overall kiwi activity, with a peak in the 9th hour after sunset. The delay in peak detections compared to AR4 recorders could indicate that camera traps are more effective at capturing kiwi during active foraging periods rather than when they are calling. Additionally, the lower detection rates of camera traps in the early hours after sunset may suggest that kiwi are more likely to be stationary or moving through denser vegetation during this period, making them less likely to trigger motion sensors. This aligns with previous studies indicating that camera traps are more effective at detecting large-scale movements and foraging behaviours, whereas acoustic recorders provide a better measure of vocal activity (Marsland et al., 2019).

Between the 6th and 10th hours after sunset, both methods showed moderate and consistent detection rates, indicating that kiwi remained active during this period. The similarity in detection trends suggests that kiwi movement and vocalisation behaviours were occurring at comparable levels, making this a transitional phase in their nightly activity. After the 10th hour, detections declined for both AR4 recorders and camera traps, with minimal activity recorded beyond the 12th hour after sunset. These decreases likely correspond to a period of reduced movement as kiwi rest or engage in less detectable behaviours.

One possible reason for the differences in detection patterns is the sensitivity of each method to different types of kiwi activity. The lower kiwi detection rate in camera traps may also be influenced by placement limitations, as kiwi are known to move through dense undergrowth, which may obstruct visibility and reduce detection efficiency. Additionally, kiwi may vocalise from locations that are beyond the range of the cameras but still within the range of the AR4 recorders, contributing to the higher detection rate of the latter.

These findings highlight the complementary nature of acoustic recorders and camera traps in monitoring kiwi activity. While AR4 recorders provide insights into kiwi vocalisation patterns and potential social interactions, camera traps offer valuable data on physical movement and foraging behaviour. Using both methods together allows for a more comprehensive understanding of kiwi activity and behaviour across different time intervals. Future research could explore whether these differences hold across different seasons and habitat types, as well as whether kiwi behaviour changes in response to environmental factors such as temperature or predator presence.

Chapter 4

Presence of Other Species in the Orchards, General Conclusions and Future Research

Plate 5.1 – A brown kiwi resting in the wooden nesting box. Photo by author.

4.1 Introduction

This final chapter differs from the previous in that is not a true data chapter and thus does not follow the pattern of a research paper. I tie together the results of the thesis and provide ideas for research, and provide advice to orchardists on ways to attract kiwi to their orchards. One big issue to have kiwi in orchards is the presence of their introduced predators and competitors. Previous studies have shown that kiwi feed on a variety of invertebrates, including crop pests (Dixon 2015; Watt, 1971). If kiwi presence in orchards is associated with reduced pest predator populations, then they could act as a natural pest control agent for invertebrates. However, factors such as the presence of predators, habitat suitability, and gardening practices may affect their effectiveness. Therefore, in this chapter, I look at the presence of invertebrate pests and introduce predators captured by the same camera traps used in Chapter 3 to study kiwi, using heat maps to investigate their overlap and likely effects. At the end of the chapter, I provide "Advice for vineyards and orchards", suggesting improving kiwi habitat while maintaining pest control. Environmental influences such as soil condition and pesticide use are discussed in the section on potential factors to consider. Finally, the Future Research section outlines key areas for further research to improve conservation and land management strategies. By integrating these perspectives, this chapter assesses the potential of kiwi as a natural pest regulator and identifies ways to optimise its role in horticultural ecosystems.

4.2 Discussion

4.2.1 Overall Results from Chapters 2 and 3

The findings from Chapters 2 and 3 contribute to a comprehensive understanding of the movements, habitat use, and diet composition of the North Island brown kiwi at the different study sites. Data from pitfalls, camera traps and acoustic recorders provided insights into the ecological interactions between brown kiwi and their surroundings, including the availability, behavioural patterns and spatial distribution of invertebrates.

I monitored the movements of the birds in the orchards using camera traps. The distribution of kiwi activity varied between sites, with the highest number of kiwi recorded at the smallest orchard and the lowest at the largest. The activity of kiwi was mainly observed in bush areas, with significantly fewer detections in orchard habitats in most of the study sites. Seasonal variation in kiwi activity was obvious, with capture rates highest in the summer and decreasing in the fall and winter. In both orchard and bush environments, peak activity occurred approximately 9 hours after sunset. Behavioural analyses showed that kiwi mainly engaged in foraging and prey-handling activities, with differences in behaviour found in different habitat types. Foraging behaviours were more frequent in the bush areas, although prey-handling behaviours were more common in the orchards. Mean capture rates for foraging and prey handling varied across the study sites, with capture rates in the bush areas being higher than those in the orchard areas.

Using autonomous recording units, I estimated the density of kiwi at Craigmore in two different ways. First, I looked at the largest number of kiwi captured in recordings during a 10-minute period, estimating the presence of two pairs in the 95 Ha area where the recorders could detect calls. This is equivalent to 0.04 kiwi per ha. Second, I used recordings captured at more than one recorder and categorised the calls at each recorder using the degradation of sound with distance. This allowed me to locate each call on the map and then use spatial capture-recapture (SCR) to estimate the population density. I found a population density of 0.01 kiwi per ha. Both methods yielded similar results.

Dietary analysis of kiwi faeces showed a large overlap between the invertebrate fauna consumed by kiwi and those captured in traps. Coleoptera was the most detected invertebrate group in faecal samples, followed by Diptera and Hemiptera, while Orthoptera was the second most common group in trap samples. Seasonal fluctuations in invertebrate availability were observed, with the highest frequencies of Coleopteran species occurring in June. The presence of harmful invertebrate species in kiwi faeces suggests that kiwi may contribute to natural pest control in orchard systems. Using nonmetric multidimensional scaling (NMDS) analysis, I showed that there were differences in the composition of invertebrate communities among the different study sites and seasons.

Overall, kiwi showed clear habitat preferences, preferring to forage in the bush, but will also use orchard habitats to capture prey. Seasonal changes in kiwi activity and invertebrate availability suggest a dynamic relationship between kiwi behaviour and food resources. The integration of acoustic monitoring, camera traps, and invertebrate sampling provided valuable insights into kiwi ecology and highlighted the importance of maintaining suitable habitats in horticultural landscapes.

4.2.2 Kiwi Predator & Orchard Pest Heat Map

The presence of kiwi in any landscape in New Zealand depends on whether the habitats fulfil their needs of food and shelter, but also depends on the presence and activity of their predators and competitors. To analyse predator activity and their potential interactions with kiwi and orchard pests, camera capture rates were assessed across the four study sites. Heat maps were created to visually present the results, providing a clear representation of predator activity in each location.

Among the recorded species, cats (*Felis catus*), dogs (*Canis familiaris*), and stoats (*Mustela erminea*) are considered major predators of kiwi, causing significant threats to their survival. Additionally, several species were identified as potential orchard pests, including hares (*Lepus europaeus*), rabbits (*Oryctolagus cuniculus*), rats (*Rattus spp.*), mice (*Mus musculus*), and possums (*Trichosurus vulpecula*). These species may affect kiwi habitats by competing for resources, altering vegetation structure, or predating on invertebrates that are also a major component of kiwi diet. Rabbits, hares and rats can also attract cats, ferrets and dogs as prey. Predators were captured on camera at every orchard. At The Landing (Figure 4.1), the highest predator capture rates were observed at camera traps CT9 and CT3. At Craigmore (Figure 4.2), the highest predator activity was recorded at CT11, CT9, and CT6. At Puriri Park (Figure 4.3), CT3 recorded the highest predator capture rate, while at Kainui Orchard (Figure 4.4), CT3 also showed the highest predator activity. These heat maps highlight areas of increased predator activity, particularly in proximity to streams and bush-covered regions. This spatial information is critical for identifying high-risk zones for kiwi and developing targeted predator management strategies.

Figure 4.1 Brown kiwi combined predator heat map- The Landing. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

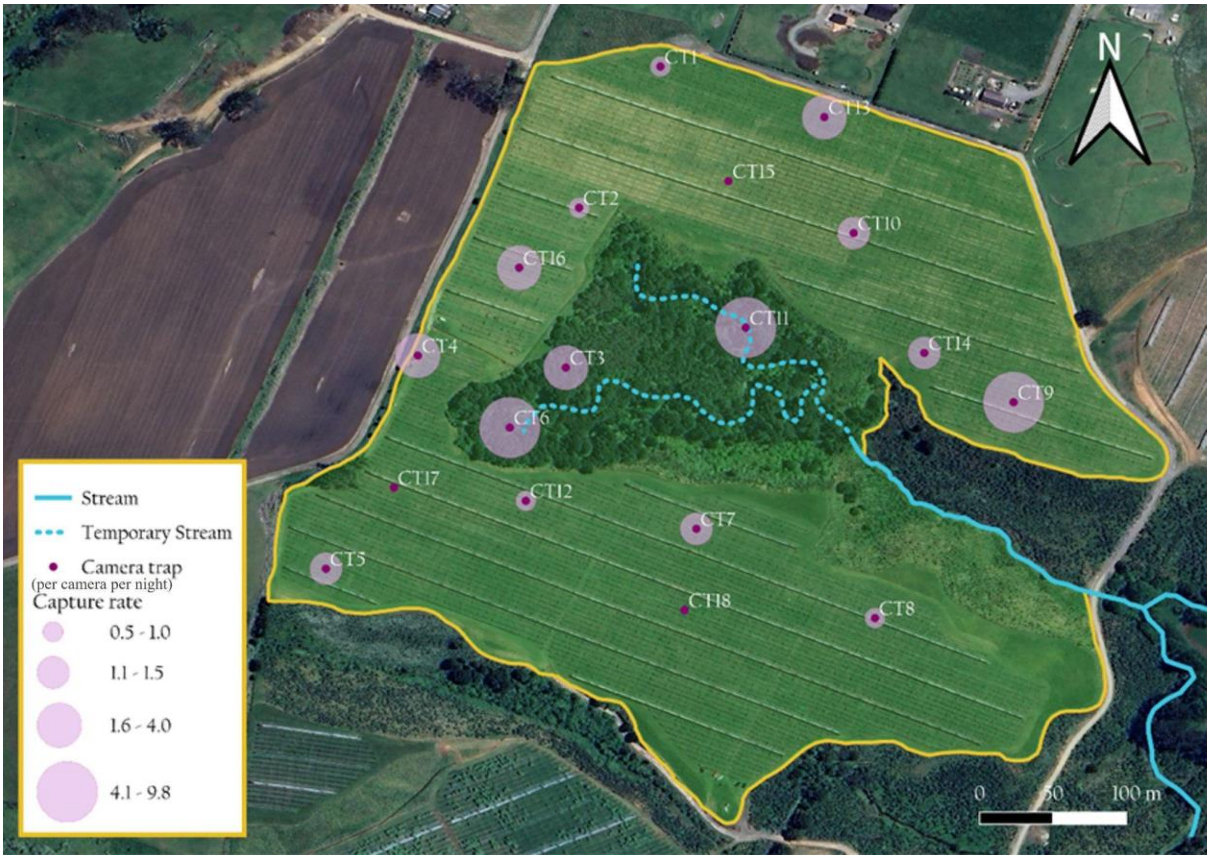


Figure 4.2 Brown kiwi predator heat map- Craigmore. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

Figure 4.3 Brown kiwi predator heat map- Puriri Park. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

Figure 4.4 Brown kiwi predator heat map- Kainui Orchard. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

At The Landing (Figure 4.5), the highest capture rates for orchard pests were recorded at CT5 and CT3. At Craigmore (Figure 4.6), CT11 and CT6 showed the highest pest activity. In Puriri Park (Figure 4.7), the highest capture rate for orchard pests was recorded at CT2. At Kainui Orchard (Figure 4.8), CT1 exhibited the highest pest activity. The heat maps reveal variations in orchard pest activity across the sites, with some areas of high activity located within the orchard zones and others near bush areas. These findings emphasise site-specific differences in orchard pest presence and their spatial distribution.

Figure 4.5 Orchard pest heat map- The Landing. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

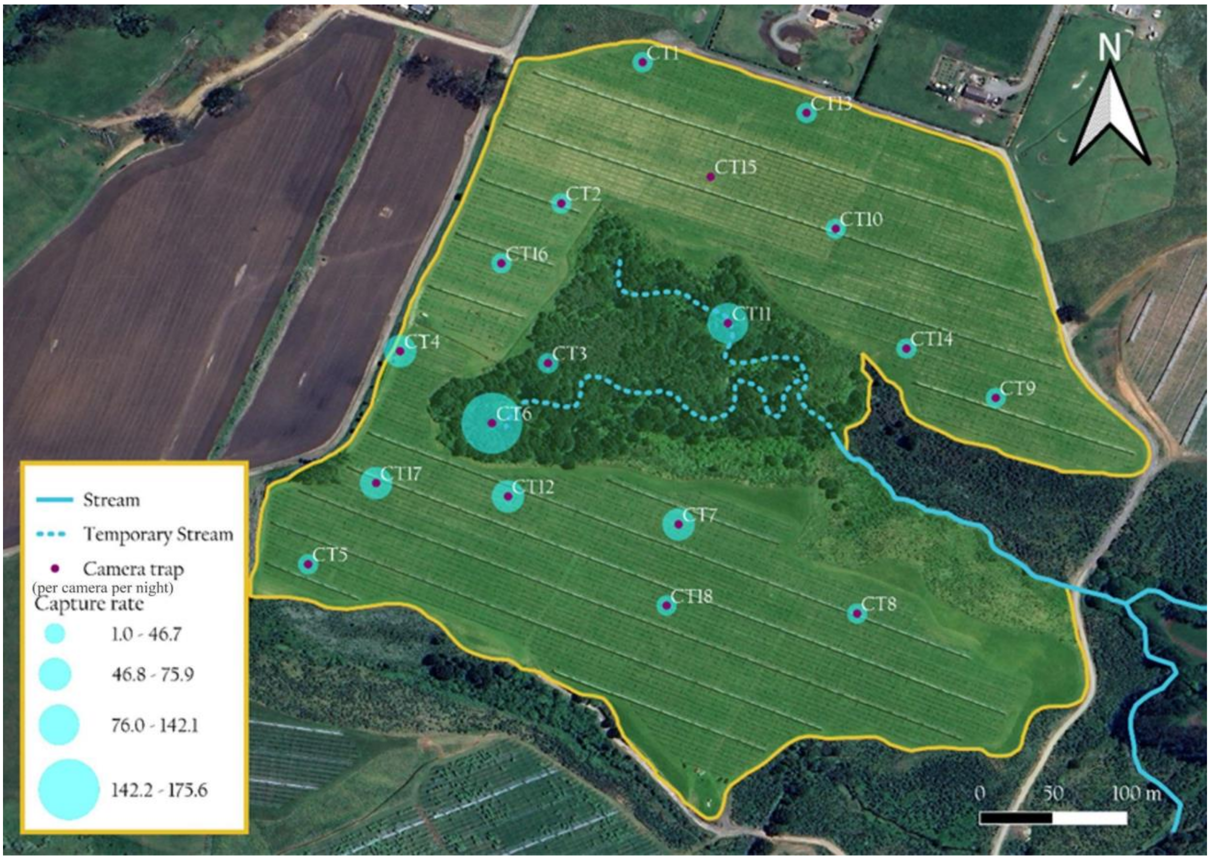


Figure 4.6 Orchard pest heat map- Craigmore. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

Figure 4.7 Orchard pest heat map- Puriri Park. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

Figure 4.8 Orchard pest heat map- Kainui Orchard. The yellow line represents the research area boundary, while the solid blue line indicates permanent streams, and the dashed blue line denotes temporary streams. Blue dots mark the positions of camera traps, and the translucent circles correspond to capture rates for predators, with larger circles indicating higher capture rates.

The heat maps generated from camera trap data provide valuable insights into the spatial distribution of predators and orchard pests across the study sites. The results highlight variations in predator presence, with higher activity concentrated near bush-covered areas and stream-adjacent locations. This pattern suggests that these environments may serve as key habitat corridors for predator species such as stoats, cats, and possums, which are known threats to kiwi populations. In contrast, orchard pest activity exhibited a more dispersed pattern, with hotspots occurring both within orchard zones and in proximity to native vegetation.

Predator activity was most pronounced in Craigmore, where capture rates were highest at CT11, CT6, CT9, and CT3. The spatial concentration of predators in these locations aligns with previous research indicating that mammalian predators prefer areas with dense undergrowth or near water sources, which provide cover and access to prey (Robertson et al., 2019). The presence of stoats at Craigmore is particularly concerning, as they are a major predator of kiwi chicks and can significantly impact population recruitment rates (McLennan et al., 1996).

Interestingly, Puriri Park recorded lower predator capture rates despite being a bush-dominated site, suggesting that habitat structure and local conservation efforts may be mitigating predator presence. This could explain why kiwi foraging activity was higher in orchard areas at this site compared to others. In contrast, Kainui Orchard exhibited a more mixed predator distribution, with high activity recorded at CT3, CT5, and CT8, which were positioned closer to bush fragments. The high frequency of possum activity in Kainui Orchard suggests that dense vegetation in the area provides good shelter and an abundant food supply, making it an attractive habitat for possums.

The presence of multiple predators in Craigmore, including stoats and cats, indicates that Craigmore may have habitat features that support predator populations, such as food availability and hiding places. In contrast, The Landing recorded fewer predators overall, which may be attributed to management practices such as mammal pest control, effectively reducing predator numbers.

While predator activity varied across sites, the heat maps suggest that specific environmental factors influence predator distribution. High predator activity near bushland and water sources indicates that these areas provide suitable cover and access to prey, making them ideal habitats for species like stoats and cats. However, reduced predator presence in Puriri Park may indicate lower food availability or a lack of suitable habitat features for stoats and possums.

Despite fewer mammalian predators, Puriri Park recorded the presence of pests such as rabbits and rats, which could indirectly affect kiwi by competing for food resources or altering habitat conditions (Department of Conservation, n.d.). This finding reinforces the complex interactions between native and introduced species in horticultural landscapes and highlights the need for comprehensive pest and predator management strategies.

The heat maps for orchard pests highlight site-specific variations in activity levels. The Landing and Craigmore exhibited the highest orchard pest activity, particularly at CT5, CT11, and CT6. These areas are located within orchard zones but are also adjacent to bushland, suggesting that pest species may be utilising both environments. The strong presence of orchard pests near native bush suggests that pest management strategies need to account for the movement of pests between habitats, rather than focusing solely on orchard interiors.

At Puriri Park, orchard pest activity was highest at CT2, which was located in an open orchard area. This aligns with previous findings that pest species such as insects and rodents may be more active in orchard settings, where fruiting trees and ground vegetation provide food and shelter. Similarly, Kainui Orchard exhibited concentrated pest activity at CT1 and CT7, which are positioned in orchard-dominated areas with limited adjacent native vegetation.

The findings from these heat maps underscore the need for integrated predator and pest management strategies in orchard environments that support kiwi populations. Given that predators are more active near bushland and water sources, conservation efforts should focus on buffer zones with targeted predator control measures, such as:

- Trapping programs for stoats, possums, and capture of feral cats in high-risk areas like Craigmore and The Landing.
- Exclusion fencing to create kiwi-safe zones and prevent predator movement between native bush and orchard areas, but make sure with sufficient predator control effort in this area.
- Regular monitoring of predator populations using camera traps to assess the effectiveness of management interventions.

For orchard pest management, the data suggest that pest populations may thrive in areas with high food availability and reduced natural predation. Sustainable pest control strategies should prioritize: 1) Integrated Pest Management (IPM) to minimise the use of chemical pesticides while effectively controlling pest species (Jones & Sullivan, 2021). 2) Biological control methods, such as encouraging native bird species like the New Zealand falcon, which were observed at some sites and could contribute to natural pest suppression (Kross et al., 2018). 3) Habitat modifications, such as increasing native vegetation cover to enhance natural predator populations that help control pests.

Overall, these results emphasise the importance of understanding spatial variations in predator and pest activity to develop effective conservation and land management strategies. The presence of predators near native bush and water sources suggests that kiwi moving between habitats may be at risk, reinforcing the need for targeted predator control in transition areas. Meanwhile, orchard pest hotspots in areas with reduced native vegetation connectivity highlight the importance of habitat diversity in maintaining ecological balance.

Future research should focus on assessing long-term trends in predator and pest dynamics and examining how different land-use practices influence kiwi survival and habitat selection in horticultural landscapes. Additionally, exploring the impacts of conservation interventions, such as enhanced predator control and habitat restoration, will be critical for optimising kiwi conservation efforts in managed agricultural environments.

4.2.3 Potential Factors that need to be considered

The ability of the North Island brown kiwi to provide ecosystem services in vineyards and kiwifruit orchards is influenced by a range of environmental and management factors. Understanding these factors is critical to optimising kiwi conservation efforts while maintaining orchard productivity. Three key factors to consider are soil type, gardening management, and pesticide use.

Soil quality plays a crucial role in determining the availability of invertebrates, which are the main food source for kiwi. Loam soils are rich in organic matter and water, supporting higher invertebrate diversity, and making them ideal for kiwi foraging (Briones et al., 2014). These soils provide better conditions for earthworms, beetles and other soil-dwelling invertebrates, ensuring a steady food supply for the kiwi. In contrast, sandy or compacted soils tend to be nutrient-poor and dry, resulting in fewer invertebrates and may be less suitable for kiwi.

Maintaining high-quality soil conditions is not only beneficial for kiwi, but also for horticultural productivity. Soil management practices, such as cover crops, reduced tillage and organic amendments, can improve soil structure (Carrera et al., 2007; Cerecetto et al., 2021), increase invertebrate populations and create a more favourable environment for kiwi foraging.

Gardening practices, including pruning, ground cover maintenance, and irrigation, significantly affect habitat structure and invertebrate availability. These practices may improve or destroy kiwi habitat, depending on how they are implemented. According to Hollinshead et al. (2024), orchard management directly affects habitat suitability for kiwi, especially environmental disturbance and vegetation cover. Management practices that can improve conditions in orchards are discussed below.

Ground cover management: Maintaining native vegetation as ground cover can support a diverse invertebrate community and provide additional foraging opportunities for kiwi. Minimise disturbance during the breeding period: 1) Concentrating the timing and frequency of human activity in orchards during the key kiwi reproductive months can enhance habitat stability and reduce stress on nesting kiwi. 2) Create microhabitats: Ensure that the orchard has a wide variety of plants to increase the diversity of invertebrates, which in turn aids kiwi foraging. Leaving woody debris, logs, and leaf litter can also provide microhabitats for kiwi prey. Piles of logs or hollow logs also offer roosting and nesting sites. By adopting kiwi-friendly horticultural management strategies, orchardists can support biodiversity and sustainable agricultural production.

Pesticide use reduces the availability of invertebrates (Gunstone et al., 2021), the main food source of kiwi, and may cause effects on their foraging behaviour. It is well known that the use of conventional pesticides can reduce populations of ground-dwelling invertebrate species and disrupt natural food webs (Todd et al., 2016). Orchards that rely too heavily on chemical pesticides may inadvertently reduce the food supply for kiwi, thereby making their habitat less attractive to them.

In contrast, organic and integrated pest management (IPM) methods are less harmful to non-target invertebrates (Elhamalawy et al., 2024; Fuller et al., 2005), ensuring that kiwi still has a natural food source. IPM strategies, such as biological pest control and habitat manipulation, can reduce pest populations effectively while maintaining ecological balance. By adopting a low chemical input approach, orchard managers can create a more sustainable environment that is beneficial for kiwi conservation and orchard productivity.

To maximise the presence and ecological role of kiwi in a horticultural landscape, soil conditions, orchard management practices, and pesticide use must be considered. Maintaining high-quality soils, implementing biodiversity-friendly orchard practices, and reducing pesticide use can improve kiwi habitat suitability while also benefiting overall ecosystem health. Future research should explore the long-term effects of these factors to better understand how to create horticultural environments that support kiwi conservation and agricultural sustainability.

4.2.4 Recommendations to Advise to Vineyards & Orchards about enhancing Kiwi Habitat in Orchards and Pest Control

The North Island brown kiwi is a key species in New Zealand’s ecosystem and has the potential to provide valuable ecosystem services in horticulture, including vineyards and kiwifruit orchards, particularly in controlling invertebrate pest populations. However, for kiwi to thrive in these environments and maximise their ecological contributions, habitat enhancement and sustainable management practices are necessary.
Implementing strategies that make horticultural landscapes more kiwi-friendly can improve biodiversity while maintaining orchard productivity. Several key approaches can be adopted to support kiwi populations:

Introduced mammal control: The most effective method to increase and maintain kiwi populations is introduced mammal control (Robertson et al. 2011). The use of traps and toxins is well-documented in New Zealand to reduce predators. In addition, developing a program to regularly control predators can protect adult kiwi and also improve the low survival rate of chicks (Department of Conservation, 2019). The predator control plans can be developed with participating orchards, and a regular on-site monitoring and trapping system can be established.

Enhancing Habitat Quality: One of the most effective ways to attract kiwi to vineyards and orchards is to maintain native vegetation, which serves as a habitat for invertebrates, a crucial food source for kiwi. By preserving or reintroducing native ground cover and shrub layers, orchard managers can improve habitat conditions, making these environments more suitable for kiwi foraging.

Promoting Organic Practices: Research by Briones et al. (2014) highlights that organic farming practices contribute to healthy soil fauna, providing a stable and diverse food supply for kiwi. Organic approaches that reduce chemical inputs not only benefit kiwi populations but also support broader ecosystem health by sustaining soil biodiversity and invertebrate abundance.

Implementing Sustainable Pest Control: Traditional pest control methods often rely on chemical pesticides, which can negatively impact non-target invertebrates, reducing food availability for kiwi. Sustainable alternatives such as IPM and biological control methods are effective while minimising ecological disruption (Todd et al., 2016). These strategies reduce reliance on chemical pesticides, allowing kiwi populations to benefit from a stable and natural food web.

Providing Nesting Opportunities: Maintaining undisturbed patches of leaf litter, logs, and dense vegetation can provide natural nesting and shelter opportunities for kiwi.

Restoring Native Vegetation Buffers: Maintaining or reintroducing native plant buffers around orchards can increase habitat connectivity, allowing kiwi to move safely between different environments.

There is growing evidence that conventional farming practices, particularly those with high pesticide use, negatively impact soil biodiversity and invertebrate populations (Todd et al., 2016). In contrast, organic orchards tend to support richer soil fauna, providing more food for kiwi and contributing to natural pest control. Encouraging low-chemical input practices or adopting organic farming techniques could improve soil health significantly, support kiwi populations, and enhance biodiversity in orchards.

By adopting biodiversity-friendly management practices, orchard and vineyard owners can create environments that not only support kiwi conservation but also promote sustainable agricultural productivity. Future research should explore further how different farming approaches influence kiwi behaviour and habitat use, ensuring that conservation efforts align with horticultural management objectives.

4.3. Research Recommendations

While this research provides valuable insights into the role of the North Island brown kiwi in horticultural landscapes, several areas require further study. Future research should focus on quantifying kiwi ecosystem services, exploring different orchard types, assessing potential impacts on soil structure, and implementing long-term monitoring strategies. Expanding research in these areas will enhance our understanding of how kiwi interact with horticultural environments and lead to more effective conservation and land management strategies.

To better understand the impact of kiwi on vineyards and kiwifruit orchards, future research should include fencing experiments, where parts of an orchard are enclosed to prevent kiwi access. These fences need to be carefully designed to exclude only kiwi, without restricting other similar or larger-sized animals from getting in the fence to avoid confounding effects. By comparing fenced and unfenced areas, the researchers could measure the direct impact of kiwi on:

- Pest populations – Determining whether kiwi presence results in a reduction in invertebrate pest populations.
- Soil health – Assessing changes in soil aeration, nutrient cycling, and organic matter accumulation resulting from kiwi foraging behaviour.
- Plant diversity – Investigating whether kiwi activity influences plant growth and ground cover composition.

By assessing these differences, fencing experiments can quantitatively measure the contribution of kiwi to ecosystem services, strengthening the case for their conservation in horticultural settings.

Most research on kiwi in horticultural landscapes has focused on vineyards and kiwifruit orchards. However, kiwi behaviour and habitat preferences may vary across different types of orchards. Future research should consider:

- Organic orchards – Investigating whether minimal pesticide use leads to more natural kiwi foraging behaviour and improves invertebrate availability.

- Orchards with varying canopy cover – Assessing whether tree density and vegetation structure affect kiwi movement and habitat use.
- Different fruit crops – Exploring whether kiwi exhibit habitat preferences based on food availability, soil conditions, and orchard management practices.

Research in these areas will help determine the optimal orchard conditions to support kiwi conservation while minimising disruptions to horticultural productivity.

While the benefits of kiwi in horticulture landscapes are well recognised, potential risks or unintended impacts must also be considered. Several factors require further investigation:

1. Effects of kiwi on soil structure – Digging and foraging behaviours may alter soil composition, potentially affecting plant health and crop growth (Maisey et al., 2025).
2. Effects of surrounding landscape – Orchards adjacent to native bush may experience higher kiwi visitation, which could lead to differences in pest suppression effectiveness compared to more isolated orchards.

Understanding these ecological interactions is essential for developing balanced conservation and management strategies.

Soil conditions play a crucial role in kiwi foraging success and pest control efficiency. Future research should investigate:

1. How does different soil composition (e.g., clay, sand, loam) affect kiwi foraging success? – Softer loamy soils may be easier for kiwi to probe, increasing their chances of acquiring invertebrate prey.

2. Effects of soil compaction – Harder soils may limit kiwi’s ability to dig, reducing foraging efficiency and affecting prey abundance (Cunningham et al., 2011).
3. Relationship between soil moisture and invertebrate abundance – Wet soils may support higher prey densities, influencing the distribution and foraging behaviour of kiwi.

Including multiple soil types in future studies will provide valuable insights into the relationship between soil type, kiwi activity, and pest control.

To ensure the sustainable presence of kiwi populations in horticultural landscapes, long-term monitoring programs should be established. These efforts should aim to:

- Involve local communities in conservation efforts – Encouraging orchard owners and local communities to participate in monitoring and habitat improvement can foster greater support for kiwi conservation.

Additionally, my findings on calling pattern variations contribute to this field of study, aligning with ongoing research (Diniz et al., 2024). Further investigations could explore how environmental factors influence vocalisation patterns and whether call variations are linked to habitat conditions, breeding cycles, or social interactions.

By addressing these research gaps, future studies can develop evidence-based strategies that enhance kiwi conservation while supporting sustainable horticultural management. Combining scientific research with practical conservation approaches will ensure that kiwi populations continue to thrive in horticultural landscapes.

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