Testing monitoring techniques for banded rails (*Hypotaenidia philippensis assimilis*)
in coastal mangrove habitats of New Zealand

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This thesis is dedicated to my nana, Annette Johnson.
For being a constant source of inspiration and encouragement and always pushing me to follow my dreams. Your unwavering support has been my guiding light, and I am grateful for your love and guidance. Thank you for holding me a little tighter when I needed it the most. Nana, this is for you.

"Advance confidently in the direction of your dreams, and endeavour to live the life you have imagined…"

Thoreau

Habitat preferred by the banded rail (*Hypotaenidia philippensis assimilis*) in the upper Waitematā Harbour, Auckland, New Zealand. Photo: I. Mallinder-Capamagian, September 2022.

ABSTRACT

The banded rail (*Hypotaenidia philippensis assimilis*) is a cryptic and elusive bird that inhabits wetlands and coastal mangrove forests in New Zealand, and is currently listed as 'At Risk - Declining' due to habitat loss and predation. Due to their elusive behaviour, monitoring this species is problematic using traditional methods, and as a result, little is known about their populations and distribution. Banded rails are considered a keystone species and an indicator of wetland health, making monitoring their populations and distribution crucial for effective wetland conservation and management.

To address the lack of knowledge and understanding about banded rails, I tested the applicability and reliability of three monitoring methodologies in coastal mangrove habitats. Currently, there is no standardised methodology for monitoring banded rails, and it is unknown what techniques are best suited and the most reliable for this species.

Presence/absence data were collected from 20 sites around the upper Waitematā Harbour using three main monitoring methodologies: footprint surveys, camera trapping, and call-playback surveys. I fitted a range of generalised linear mixed models to the count data collected from all three monitoring techniques to identify factors affecting banded rail detection. Results showed that the size of mangrove habitats, the presence of freshwater, and substrate quality were significant predictors of banded rail footprint frequency. Additionally, freshwater, predators, and plot location were important factors affecting banded rail detection using camera traps. Footprint surveys were found to be a reliable and cost-effective method for detecting the presence of banded rails, while camera trapping provided valuable insights into their behaviour and habitat use. Although call-playback surveys were moderately effective for detecting the presence of banded rails, they may have limitations as a standalone technique.

The results of this thesis have important implications for the conservation and management of wetlands in New Zealand. By testing and comparing various monitoring techniques, this research offers valuable insights into the ecology and behaviour of the banded rail, a keystone species and indicator of wetland health. The findings may inform the development of more effective monitoring protocols for banded rails and other cryptic wetland species, contributing to the existing literature on wetland ecology and conservation.

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TABLE OF CONTENTS

CHAPTER 1
General Introduction and Literature Review

1.1 INTRODUCTION

Monitoring is a crucial aspect of the management and conservation of threatened species and ecological communities (Robinson et al., 2018). It helps conservation managers to understand population trends, evaluate the effectiveness of conservation management, and identify drivers of population decline (Legge, 2018). However, developing effective monitoring protocols for cryptic or difficult-to-detect species is challenging for managers and can lead to unmonitored or poorly monitored species and ecological communities (Williams, 2016), which are often considered 'data deficient' as a result.

Therefore, it is imperative that conservation managers identify and apply appropriate monitoring tools to understand population trends and address causes of population decline. Wetland (marsh) birds, such as Rallidae (rails and crakes) and Botaurinae (bitterns), are particularly difficult to monitor due to the dense habitat they occupy, small population size, restricted range, and cryptic behaviours (Znidersic, 2019). Despite their global distribution, Rallidae are generally poorly represented in ornithological research literature (Brambilla & Jenkins, 2009; Znidersic, 2019). Survey effort, conservation attention, and resources are usually focused on highly threatened or charismatic species that engage public interest, and conservation monitoring is rarely focused on rails explicitly (Brambilla & Jenkins, 2009).

Threatened or rare species are often difficult to monitor because of low population densities and erratic population fluctuations (Lindenmayer et al., 2020). Development of effective monitoring techniques for threatened species can be even more complex when the species exhibits cryptic characteristics or is difficult to detect in its environment (Garrard et al., 2015; Williams, 2016). To understand population trends and address the underlying causes of population decline, conservation managers must prioritise the selection and implementation of appropriate monitoring tools for such species. This is particularly crucial for wetland bird species like rails, which face additional threats from habitat loss and climate change as wetlands are one of the most threatened ecosystems globally (Tomscha et al., 2019; Znidersic, 2019).

1.1.1 Model Species: The Banded Rail

The banded rail (*Hypotaenidia philippensis assimilis* or Moho pererū) is a model species in this thesis, inhabiting salt marsh and mangrove wetland systems in New Zealand (Beauchamp, 2015; Elliot & Graham 1989). The banded rail is currently classified as 'At Risk and Declining' under the New Zealand Threat Classification System due to habitat loss and predation (O'Donnell et al., 2021; Robertson et al., 2021). Banded rails are significant indicators of wetland health as they require high-quality habitats and a rich food supply (O'Donnell et al., 2015). In addition, they are keystone species in wetland ecosystems, contributing to nutrient cycling, seed dispersal, and regulating populations of other species (Campbell et al., 2016). The banded rail also holds cultural significance and is a drawcard for ecotourism in wetland areas, providing economic benefits for local communities (Minot et al., 2020; Taylor et al., 2021). Hence, the conservation of banded rails is crucial for maintaining ecosystem functions, protecting cultural heritage, and promoting sustainable economic development.

1.1.2 Banded Rail Distribution and Habitat

Approximately 26 subspecies of banded rail (*Rallus philippensis*) can be found throughout the Pacific, including Australia, south-east Asia and the south-west Pacific Islands (Botha, 2010). Over its whole range, banded rails inhabit a variety of habitats including forests, mangrove forests, scrublands, salt marshes, high altitude grasslands and coral islands (Elliott, 1983).

Banded rails were once widely distributed throughout New Zealand but are now confined to wetlands, mangroves and salt marshes in the northern latitudes of the North Island and a few offshore islands such as Poor Knights Islands, Three Kings and Great Barrier Island (Botha, 2010). These birds are elusive and typically seen within 10 meters of dense cover of mangroves or salt marsh habitat (Beauchamp, 2015).

In the North Island, banded rails are found mainly in coastal environments such as estuaries and harbours, and are rarely found inland except for freshwater wetlands in Northland and the Waikato (Botha, 2010). In the upper South Island, banded rails can be found in salt marshes dominated by the rush species *Juncus maritimus* (Elliott, 1987). However, in the upper North Island, salt marsh habitats have reduced due to coastal development, leaving banded rails confined to remaining patches of salt marsh, as small as 0.001 ha in size, and adjacent coastal mangrove habitats (Beauchamp, 2015). The native mangrove species (*Avicennia marina var. australasica*) found in coastal and estuarine environments of upper parts of the North Island is thought to provide banded rails with important foraging habitat and cover from aerial predators (Blayney, 2017; Botha, 2010).

1.1.3 Predation of Banded Rails

Habitat modification and predation are the main factors contributing to the decline in banded rail populations. Stoats (*Mustela erminea)* have been observed preying on nests in salt marshes in Omaha and in Nelson (Elliott, 1983; Parker & Brunton, 2004). Adult banded rails sitting on nests have been preyed upon by swamp harriers (*Circus approximans*) and cats (*Felis catus*) (Elliot, 1983). Predation by cats has been found to be a significant cause of banded rail nest failure, with one study reporting that 41% of nests failed due to cat predation (Rogers, 2019). Introduced predators such as rats (*Rattus spp.)* and possums (*Trichosurus vulpecula*) have also been identified as threats to banded rail populations, although they do not always result in population declines (Elliot, 1983).

1.1.4 Current Knowledge Gaps

Despite its widespread global distribution, Rallidae are poorly represented in ornithological research literature and survey effort and conservation attention are usually concentrated on highly threatened or charismatic species that engage public interest (Brambilla & Jenkins, 2009; Znidersic, 2019). Data deficiencies exist regarding the ecology, distribution, habitat-use, and population status of the banded rail, and few studies have focused on this species specifically. Furthermore, the banded rail has been issued two "Data Poor qualifiers" by the Department of Conservation, meaning the size and trends of the population in New Zealand is currently unknown (Robertson et al., 2021). Given this species has a conservation status of ‘At Risk – Declining’, the fundamental gaps in our knowledge of this species must be addressed.

There is a particular need for development of appropriate monitoring tools and techniques for banded rail in New Zealand (Blayney, 2017). Due to their cryptic colouration, elusive behaviour and low population density, banded rails are one of the most challenging species to survey using traditional methods such as transect counts and auditory surveys. Additionally, monitoring banded rail can be challenging due to their preference for mangrove forests as foraging habitat, which is associated with dense subtidal vegetation, silt, and boggy substrate.

These conditions make traditional monitoring methods, such as walking line transects and observing individuals, difficult to conduct. Therefore, new and innovative methods for monitoring banded rail populations in their preferred habitat should be developed.

To date, no studies have tested and compared which methods are most reliable for the monitoring of this species. Knowledge about cryptic bird species with similar ecology and habitat to banded rail should be used to develop the appropriate tools and techniques for monitoring the banded rail (Blayney, 2017). It is important that monitoring methodologies be rigorously tested and evaluated for their effectiveness in order to better direct conservation efforts. This will involve establishing standardised protocols for data collection, analysis, and reporting to ensure consistency and comparability across different studies (MacKenzie et al., 2002). Furthermore, it will be essential to involve local communities and stakeholders in the monitoring process to ensure that the conservation efforts are socially and culturally appropriate (Buckland et al., 2019). By developing and implementing reliable monitoring methods for the banded rail, we can improve our understanding of its population dynamics and take appropriate conservation actions to safeguard its future survival.

1.2 LITERATURE REVIEW: CURRENT MONITORING PRACTICES FOR CRYPTIC WETLAND AVIFAUNA AND BANDED RAILS (*Hypotaenidia philippensis assimilis*)

Currently, there is a lack of standardised monitoring methods for the banded rail (*Hypotaenidia philippensis assimilis*) in New Zealand. The purpose of this review is to examine monitoring methods used for cryptic marsh birds, particularly those in the Rallidae family, and to consider options for long-term monitoring of the banded rail. This review will draw on both past and recent literature, including international studies dating back to the 1980s.

To provide context, this review will begin by identifying the general cryptic characteristics of marsh birds, with a focus on the Rallidae family and how these characteristics compare with the banded rail. This will provide the necessary foundation for understanding why certain monitoring methods may be more effective for different species, and how the cryptic characteristics of species may present challenges to monitoring efforts.

The review will then examine the monitoring tools that have been used to inform the conservation of rails, followed by an overview of the techniques used for banded rails in New Zealand over the past 40 years. After examining the monitoring methods, the review will discuss the potential applicability of methods used for other species to monitor the banded rail. Finally, the review aims to identify potential tools that have not yet been tried on banded rails but have been used to detect and monitor other similar species.

The closely related Cocos buff-banded rail (*Gallirallus philippensis andrewsi*), which shares similar habitat and cryptic characteristics, can provide valuable insights into monitoring the banded rail in New Zealand (Woinarski et al., 2016; Znidersic, 2019). By reviewing the conservation of the Cocos buff-banded rail, we can draw comparisons and consider the potential applicability of its monitoring methods to the New Zealand banded rail.

1.2.1 Literature Search

I used a combination of online databases and search terms to identify peer-reviewed articles related to monitoring cryptic wetland avifauna, with a particular focus on the Rallidae family and the banded rail (*Hypotaenidia philippensis assimilis*) in New Zealand. I conducted a literature search using two primary online databases, Google Scholar and Web of Science. I used the following search terms and combinations of key words: “monitoring”, “cryptic”, “cryptic characteristics” and “marsh birds” or “wetland birds” or “wetland avifauna”. Additionally, I used specific keywords related to the Rallidae family and the banded rail, including “banded rail”, “*Hypotaenidia*”, “*Hypotaenidia philippensis assimilis*”, and “*Gallirallus*”. I also used additional search terms including “wetland conservation”, “habitat management” and “population monitoring” to help identify additional relevant sources related to wetland avifauna conservation, management, and monitoring.

To further refine the search, I considered additional variables that could affect the detectability of wetland avifauna. These variables included survey effort, replicates, season, and total survey time. For each study that met my search criteria, I investigated the survey methods used and any variables considered in the survey design. I also considered the geographic location of each study and whether the monitoring methodology used in that study was applicable to the wetland avifauna in New Zealand. I excluded any sources that did not meet the criteria or were not relevant to the topic of this literature review. To ensure the information was current, I focused on studies published in the last 30 years, while still considering relevant studies published prior to 1990.

1.2.2 Cryptic Characteristics of Wetland Avifauna

Cryptic wetland avifauna are species that are difficult to detect in their environment and are challenging to monitor using traditional surveying techniques. According to the comprehensive classification proposed by Williams (2016), cryptic species fall into four primary categories: visually cryptic, characterized by their visual resemblance to their surroundings; behaviourally cryptic, exhibiting behaviours that minimize detectability; spatially cryptic, adept at utilizing the environment to conceal themselves; and temporally cryptic, displaying patterns of activity that align with periods of reduced visibility. Marsh bird species often employ a combination of these cryptic strategies, further complicating detection efforts. By precisely identifying the specific type of crypsis employed by these avian species, conservation managers may be able to overcome the inherent monitoring challenges associated with each category.

Visually cryptic species tend to occupy dense vegetation and have plumage that allows them to blend in well with their surroundings. For example, the Australasian bittern (*Botaurus poiciloptilus)* is an endangered wetland bird found in New Zealand, Australia, and New Caledonia (Williams & Brady, 2014). Its streaky beige and brown plumage helps it to camouflage in the dense vegetation, and when approached, it will either move away quietly and slowly, adopt a 'freeze' pose, or flatten its torso on the ground to avoid detection (Williams, 2016). Due to its visually and behaviourally cryptic nature, traditional visual survey methods such as point counts or mark-resight may be ineffective for monitoring this species, and current monitoring practices are heavily reliant on acoustic surveys.

Species can also be spatially cryptic if they occupy inaccessible habitats, leading to logistical constraints when it comes to monitoring (Williams, 2016). Marsh crake (*Porzana pusilla affinis*), for example, are small, highly cryptic, and rarely seen, making them one of the most under-researched marsh bird species endemic to New Zealand (O'Donnell, 2018). They inhabit a variety of wetland types, including *Carex secta* and raupō (*Typha orientallis*) swamp systems, which are often remote and challenging for surveyors to access (Kaufmann, 1988). In addition, marsh crake are also temporally cryptic as they usually only call at dusk and at night, limiting detection primarily to acoustic monitoring methods such as call counts and playback surveys (O'Donnell, 2018). For some species such as Eurasian coots (*Fulica atra*), calls can be heard year-round, making surveying less challenging (Randler, 2006).

1.2.3 Cryptic Characteristics of Banded Rails

Banded rails are challenging to detect due to their various cryptic characteristics. They are visually and behaviourally cryptic, as they inhabit dense vegetation and exhibit slim bodies that allow them to move quietly and quickly through the environment (Elliott, 1983; Heather & Robertson, 2005).) Additionally, their plumage enables them to blend in with their surroundings, making them difficult to spot (Heather & Robertson, 2005). Unlike some other wetland bird species, banded rails do not freeze when approached but quickly dart for cover (Elliott, 1983).

Banded rails are also spatially cryptic as they inhabit thick coastal vegetation, such as salt marshes, rushes, and mangrove forests, which are difficult to access (Blayney, 2017). This characteristic creates logistical challenges for monitoring, such as requiring specialist skills and a high level of fitness to navigate the habitat.

Finally, banded rails are temporally cryptic, as they are most active during dawn and dusk (Marchant & Higgins, 1993). Thus, detecting them outside of these limited time frames can be challenging. Banded rails' temporal crypticity further adds to the complexity of studying and understanding these elusive birds.

1.2.4 Current Monitoring Methods Used for Cryptic Wetland Avifauna

The monitoring of wildlife populations can be broadly categorised as either complete counts (census) or incomplete counts (Gregory et al., 2004). Complete counts require no correction for detectability because all individuals within a defined sampling region are detected (Greene, 2012). In contrast, incomplete counts do not require that all individuals are counted within a sampling unit (Williams, 2016). For elusive or rare species, incomplete counts are often used as not all individuals can be detected during sampling.

To date, auditory surveys (Taylor & van Perlo, 1998), line transects (Woinarski et al., 2016), and rope dragging surveys (Colyn et al., 2017) have been the most widely utilised methods for surveying Rallidae. However, recent studies have explored other methods such as radio telemetry (Jedlikowski & Brambilla, 2017), camera trapping (Znidersic et al., 2019) and environmental DNA (Neice & Mcrae, 2021).

The methods currently used to detect cryptic wetland avifauna primarily rely on vocalisations. Other conventional avifauna monitoring methods such as point or transect counts and mist-netting are unsuitable for cryptic species as they rely on visual detection of the animal (Brandes, 2008). Table 1 provides an itemised comparison of the efficiency of each technique, including the advantages and limitations for each. By assessing the strengths and weaknesses of current monitoring practices, this review aims to identify gaps and opportunities for improving the detection and monitoring of cryptic wetland avifauna, including banded rails.

Table 1.1: Overview of the monitoring methods discussed in this review with a brief description of their methodologies and the advantages and disadvantages of each.

Monitoring technique	Description and advantages/disadvantages	References
Call counts	Observers count the calls of species and individuals within a designated area with or without the use of recorded calls (playback). Advantages: Well documented method; low material cost; easily standardized Disadvantages: Observer bias that may lead to underestimates; require large survey effort over multiple visits; certain calls may not elicit a response	(Beauchamp, 2015; Neice & Mcrae, 2021; Tomlinson & Todd, 1973; Williams, 2016)
Acoustic sensors (autonomous recording units)	Passive acoustic sensors record all sounds emanating from a specific location (including calls of the target species) which creates a "soundscape" that is unique to the area. Advantages: Yields large amounts of data over long durations; reduced observer bias; minimal species and habitat disturbance; low labour cost Disadvantages: High initial costs; requires sorting through large amounts of data	(McLeod, 2019; Williams et al., 2018; Znidersic, 2019)
Transect surveying	Researchers manually search for birds, nests or other objects while walking along a predefined transect within a study area. Advantages: Easily standardized; density and population estimates can be made; low material cost Disadvantages: Unreliable detection rates; sampling bias is possible; relies on visual detection of the target species	(Monks et al., 2021; Woinarski et al., 2016; Znidersic et al., 2019)
Capture-mark-recapture using radio telemetry	Individuals are located and captured using a pre-defined method. Radio transmitters are attached to the individuals, allowing remote detection and tracking. Advantages: Can provide insight into foraging ranges and territory size of individuals; allows tracking in remote locations Disadvantages: High initial material cost; target species must be captured first; study dependant on battery life of transmitters; does not provide information about unmarked individuals	(Jedlikowski & Brambilla, 2017; Kolts & McRae, 2017; Woinarski et al., 2016)
Camera traps	Photographs and video footage of a target species is obtained by infrared/motion cameras that are automatically triggered by movement. Advantages: Non-invasive; easily replicable; ability to capture information on behaviour; limited surveyor bias; individuals can be identified for abundance estimates Disadvantages: High initial cost; long-term deployments prone to vegetation growth; sound or light emission from cameras may affect animal behaviour	(Colyn et al., 2017; Hand et al., 2019; Howes-Whitecross et al., 2020; Meek et al., 2015; Znidersic, 2017; Znidersic et al., 2019)
Rope dragging	Observers walk through potential nesting habitat dragging a rope between them and record locations of birds when flushed. Advantages: Allows researcher to identify the location of nests, ability to cover large survey areas in a relatively short time frame. Disadvantages: Invasive survey technique; detection bias and low detection probability with some elusive species; high labour cost	(Colyn et al., 2017; Cooperrider et al., 1986.)
Environmental DNA (eDNA)	Genetic material (DNA) obtained directly from environmental samples such as water or soil, highly sensitive diagnostic PCR-based test specific to the species is used. Advantages: Non-invasive technique; allows detection of cryptic and rare species, or species in remote locations; can cover large geographic areas in a short time frame Disadvantages: Samples are affected by environmental variables and handling procedures; high material cost of specialised laboratory equipment	(Hobbs et al., 2019; Neice & Mcrae, 2021; Villacorta-Rath et al., 2022)

Call counts

Call counts are a traditional survey method that typically involve counting the calls of as many species and individuals as possible within a designated area to assess the presence and size of populations (Beauchamp, 2015). This method relies on the individuals making their presence known through vocalisation, which can often lead to underestimates of cryptic species (Williams, 2016).

The use of taped bird calls (call-playback) during call counts was established as a monitoring technique in the 1960s (Bibby et al.,1992). This method uses broadcasted calls to increase detectability (Conway & Gibbs, 2005). Call-playback was effectively used for the monitoring of the Clapper Rail (*Rallus longirostris rhizphorae*) in 1973 (Tomlinson & Todd, 1973), and has since proven successful for many other rail species (Williams, 2016). However, the call-playback method is temporally restricted and is less effective during the non-breeding season, when the birds are less vocal (Neice & Mcrae, 2021). The effectiveness of this technique also relies on the trained surveyor hearing and recognising the species (Neice & Mcrae, 2021).

Call detection via acoustic sensors

Acoustic sensors (autonomous recording units) are an effective passive monitoring tool that can yield large amounts of data over longer durations (Znidersic, 2019). This method is particularly useful for detection of rare species, species with site-specific logistic constraints, and species that vocalise during limited temporal scales such as breeding events (Williams et al., 2018).

Acoustic sensors can successfully monitor populations of a secretive wetland bird, the yellow rail (*Coturnicops noveboracensis*), in Canada (McLeod, 2019). Williams et al., (2018) also discussed the use of acoustic recorders as a long-term monitoring solution for a cryptic wetland bird, the Australasian bittern (*Botarus poiciloptilus*). The authors found that this method can solve problems associated with temporal restrictions, and site-specific logistic constraints. Limitations associated with this method are centred mostly around the high initial cost involved in the initial sourcing of recording units (Williams et al., 2018), as well as analysing large amounts of data which often relies on machine learning and artificial intelligence to identify species from audio recordings (McLeod, 2019).

So far this method has not been trialled on banded rails in New Zealand, however based on the findings of Williams et al., (2018) and McLeod (2019), this may be a viable option for monitoring banded rails due to its similar cryptic characteristics as the Australasian bittern, and also due to the restricted habitat banded rail occupy which is difficult for researchers to access and monitor using traditional methods

<u>Transect surveys</u>

Transect surveying is a commonly used monitoring method in which the observer walks at a constant pace along a predefined transect, whilst recording all birds, nests or other objects detected (Gregory et al., 2004). Density and population estimates can be made from transect counts and they have been used to monitor other rail species in a range of habitats globally (Monks et al., 2021; Woinarski et al., 2016; Znidersic et al., 2019).

Woinarski et al., (2016) found transect surveys to be a valuable tool for monitoring the population size and density of the closely related Cocos buff-banded rail (*Gallirallus philippensis andrewsi*) on the remote Pulu Keeling Island. Since 1999, consistent transect surveys have been conducted on the island to monitor long-term population changes of the species. These surveys have yielded valuable insights that have helped guide recovery plans and reintroductions of the species to the island following severe population declines resulting from human disturbance.

Due to the elusive and secretive nature of banded rails in New Zealand, combined with habitat constraints, transect counts would be challenging to conduct. The studies that have used transect counts as a monitoring method for other rail species have been conducted in habitats that are easy for the observer to traverse and rails are more easily observed, such as open grasslands (Znidersic et al., 2019), coconut palm forests (Woinarski et al., 2016), boulder fields and alpine scrub (Monks et al., 2021). As banded rails in northern New Zealand occupy mostly coastal mangrove habitat, transects would need to be set under mangrove canopy. The mud substrate commonly found under mangrove canopy makes traversing this habitat type particularly difficult and tidal movement would also restrict the time at which transects could be walked.

Radio telemetry

The technique of radio telemetry has been used to monitor elusive species and document their home range sizes in relation to ecological traits and environmental factors (Williams, 2016). Jedlikowski & Brambilla (2017) use radio telemetry to investigate factors affecting home range sizes of water rails (*Rallus aquaticus*) and little crakes (*Zapornia parva*) in Poland. Similarly, Woinarski et al., (2016) use radio telemetry to monitor the success of Cocos buff-banded rails following translocation. Radio telemetry is also used in combination with other methods such as camera trapping and transect censuses, to assess population size and track individuals (Jedlikowski & Brambilla, 2017; Woinarski et al., 2016). In addition, radio telemetry is used to study seasonal variation and sex differences in home sizes and habitat use of king rails (*Rallus elegans*) in the eastern United States (Kolts & McRae, 2017).

Despite its usefulness, radio telemetry has some limitations. The high material costs of sourcing transmitters and the limited battery life of transmitters are significant challenges. Additionally, this method requires that animals be captured first, and it does not provide information about unmarked individuals when recaptured (Williams, 2016). Furthermore, tracking during the sampling period requires the presence of researchers with a handheld receiver in the field, which incurs high labour costs, particularly if researchers are required to be in the field for multiple seasons (Kolts & McRae, 2017). Nonetheless, radio telemetry can provide valuable insights into foraging ranges, territory size, and movement patterns of elusive species in remote locations.

Camera trapping

Camera trapping is still relatively new in the field of wildlife monitoring in wetland ecosystems. This technique is effectively employed to inventory the occurrence of elusive and endangered large carnivores like tigers and leopards (Karanth et al., 2016; Odden et al., 2014), and to monitor ground-dwelling birds such as quails and pheasants (Ahrestani et al., 2021; Campião et al., 2019). Standard applications of camera trap data include documentation of species occurrence and presence/absence inventories (Znidersic, 2019). However, new applications designed to address ornithological questions regarding nest ecology, predation and behaviour appear promising for application to cryptic wetland avifauna.

Although there are no published studies on camera trapping banded rails in New Zealand, several studies on related rail species in other parts of the world have used this method to monitor presence, breeding and behaviour. For example, camera traps are used to document the presence/absence and confirm breeding of eastern black rails (*Laterallus jamaicensis jamaicensis)* in North America (Hand et al., 2019), and to monitor the presence and habitat choice of white-winged flufftail (*Sarothrura ayresi*) in a high-altitude wetland in South Africa (Colyn et al., 2017). Howes-Whitecross et al., (2020) use camera traps to monitor nest behaviour of the same rare and elusive species. Camera trapping is also proven to be successful in monitoring the survivorship of Cocos buff-banded rails post-translocation (Woinarski et al., 2016; Znidersic et al., 2019), and documenting occurrence, behaviour, breeding activity and temporal variation of Lewin's rail (*Lewina pectoralis*) on Tasman Island in Australia (Znidersic, 2017).

Certain limitations and draw-backs of this methodology include variation in high initial material costs, camera model constraints and behavioural responses of the animals to the cameras (Meek et al., 2015). Most international studies also rely on passively exploiting the target species' predictable behavioural traits, such as the regular use of tracks, to optimize camera placement and positioning (Colyn et al., 2017; Hand et al., 2019; Senzaki et al., 2021; Znidersic, 2017; Znidersic et al., 2019). Using behavioural knowledge of the banded rail, this method could potentially be adapted for use in New Zealand.

Rope dragging

Rope dragging is a technique used to survey cryptic marsh birds where a rope is used to flush birds from their habitat, allowing an observer to record the number of individuals seen and note their location (Cooperrider et al., 1986). Limitations of this method are centred mostly around low detection probabilities due to the reluctance of some Rallidae species to take flight or flush (Colyn et al., 2017). Although rope dragging is an accepted method of surveying cryptic marsh birds, due to the invasive nature of the technique, other monitoring methods are preferred (Colyn et al., 2017). Rope dragging may not be applicable to banded rail populations in the northern regions of New Zealand, as these birds prefer dense mangrove habitats that can impede the dragging of ropes.

eDNA:

A 2021 study on black rails (*Laterallus jamicensis*) explored a robust and efficient method of monitoring that provides promise for New Zealand's banded rail (Neice & Mcrae, 2021). A highly species-specific quantitative PCR assay was developed to detect environmental DNA (from here 'eDNA') in water samples collected from previously identified black rail habitat. The method successfully amplified black rail eDNA from 47% of the environmental samples taken. In comparison, auditory surveys (call-playback) conducted by the researcher at the same sampling site produced a detection rate of only 2% (Neice & Mcrae, 2021).

While this technique is promising for monitoring other cryptic rail species, limitations may arise when implementing this methodology in banded rail studies. Neice & Mcrae (2021) noted that multiple environmental factors including water depth, air temperature and salinity, as well as sampling and handling procedures affect eDNA detectability. Another consideration is the material cost involved in specialised laboratory equipment that is required for eDNA assessment. Additionally, this technique may need to be adapted for use in mangrove-dominated habitats in order to be used for northern populations of banded rail in New Zealand, which prefer these types of habitats.

Few studies have attempted to detect eDNA from birds, however this technique could prove invaluable for other elusive species that are difficult to detect in visually concealing habitats using traditional surveying methods. This method could be promising in detecting species where little is known about their behaviour and ecology such as the banded rail. The efficiency and statistical robustness of eDNA as a monitoring technique suggest that this method would be valuable for banded rail conservation in New Zealand.

1.2.5 Current Monitoring Practices Used for the Conservation of Banded Rails in New Zealand

Very little literature exists regarding the monitoring methods used for banded rails in New Zealand. Footprint surveys (Botha, 2010; Elliott, 1983) and call detection with or without use of playback recordings (Beauchamp & Chambers, 2000; Elliott, 1983) are some of the few methods that have been used. These current monitoring practices can provide presence/non-detection inventory information through incomplete counts. However, they lack the ability to provide accurate population density estimates.

Footprint surveys

Footprint surveying is a traditional monitoring method that is used for the inventory of banded rails in Nelson, Whangarei and the Bay of Plenty (Beauchamp, 2015; Botha, 2010; Elliott, 1987). Non-invasive methods such as footprint tracking are particularly useful when studying cryptic, rare or low-density species that are difficult to detect using standard monitoring methods such as trapping (Russell et al., 2009). Footprint surveys can be used to detect the presence or absence of a species within a defined sampling area (Thompson, 2013). Accurate estimates of species presence are required when ecologists study rare or cryptic species, as it allows managers to identify areas of significant habitat where a species might reside. However, this method can be labour intensive and is dependent on tide state, recent weather events, the ability of substrate to hold prints and the activity levels of the birds (Beauchamp, 2015; Elliott, 1983).

Footprint surveys can be used to gather information on the ecology of the species, as well as determining presence. Elliot (1987) uses footprint surveying to investigate banded rail habitat use in a saltmarsh habitat in Nelson. The author (Elliot, 1987) installed footprint stations containing boxes of soft sand to determine the rate at which banded rail footprints accumulate in different habitat types. Elliot (1987) was able to use footprint surveying to gather information about banded rail behaviour, where these surveys revealed that the activity of the birds peaked in the morning and evening, with low activity in the middle of the day. Another study by (Botha, 2010) uses footprint surveying along transect lines to determine habitat preference and foraging distances of banded rails within mangrove habitat.

While target species' presence can often be confirmed, it is generally impossible to confirm species' absence. An observed absence may simply be the result of the survey method failing to detect the presence of the species that is actually resident at the location (MacKenie, 2009). For example, the species was currently elsewhere within its home range, or failed to be detected within the survey period. This can lead to obtaining "false absences". To minimise the chance of obtaining a false absence, multiple surveys within a relatively short time-frame need to be conducted at a site (Williams, 2016).

Call count method

The call count method is another technique used to gather inventory information on banded rails in New Zealand. Call counts without the use of playback are used to investigate banded rail presence and occupancy in salt marsh and mangrove systems in northern New Zealand (Beauchamp, 2015). This method relies on the ability of observers to hear the vocalisations of banded rails, which can be challenging due to their cryptic nature and reluctance to vocalise.

Calls cannot be interpreted to pair status as banded rails do not appear to call with duets or move around together like other rail species such as the weka (*Galirallus australis*) and spotless crake (*Zapornia tabuensis*) (Beauchamp, 2015; Kaufmann, 1988). Therefore, call counts are currently used to assess presence or absence only and further research is required to find out if call counts can be used to determine banded rail density.

The call-playback method is also used to detect the presence of banded rails in salt marshes and coastal freshwater wetlands in Nelson (Elliott, 1987). However, the study noted that banded rails were seen in locations where there was no response to broadcasted calls, indicating that lack of response should not be taken as conclusive evidence that individuals are not present.

Given the limitations of the call count method, including the need for skilled observers and the difficulty of detecting low-volume calls, it is best used in combination with other monitoring techniques such as footprint surveys and trapping to provide a more comprehensive picture of banded rail populations. Nevertheless, call counts remain a valuable method for monitoring banded rails, relying on vocalizations to detect their presence and assess their numbers.

1.2.6 Conclusions and Recommendations

The literature surrounding population monitoring of cryptic wetland birds is vast, however in the case of banded rails, there is a lack of definitive long-term monitoring techniques (Blayney, 2017). Several techniques that were discussed as being effective for the conservation management of rail species outside of New Zealand may be inappropriate for the use in the monitoring of banded rails, mainly due to the unique habitat occupied by this species in some areas. Banded rail are habitat specialists, occupying dense habitats that are difficult to access and navigate, which needs to be considered when exploring options for monitoring. The majority of international studies focus on species that inhabit wetlands with vegetation dominated by sedge grasses or salt marsh, which is relatively easy to traverse in comparison to the dense coastal mangrove forests often occupied by the banded rail.

Several international studies use a combination of monitoring techniques to gather additional information about the target species. Tracking of individuals via radio telemetry is combined with the use of camera traps to monitor short term population persistence following translocation of Cocos-buff banded rails to a remote island by multiple authors (Jedlikowski & Brambilla, 2017; Woinarski et al., 2016; Znidersic et al., 2019). By using a combination of methods, researchers are able to investigate the short, mid and long term effects of reintroduction and determine the success of the translocation program. Some studies also combine these two techniques with transect counts to assess the persistence of the reintroduced birds and recruitment of new individuals, and to take censuses of population size of Cocos buff-banded rail (Znidersic et al., 2019), and to monitor the breeding status and confirm the presence of Swinhoe's rail (*Coturnicops exquisitus*) (Senzaki et al., 2021). Depending on the study objectives, the use of multiple monitoring techniques might be advantageous for conservation managers, although the labour, time and material costs involved in implementing multiple techniques must also be considered.

This review focused on case studies of the Cocos buff-banded rail, chosen for its similar life history to the New Zealand banded rail. The camera trapping technique, which is effective for the conservation management of Cocos buff-banded rail, shows promise for the monitoring of banded rail and should be considered in future research. The method has been used to gather information on behaviour, habitat use and has been used as a monitoring tool to determine population density of other cryptic wetland birds (Znidersic et al., 2019). Camera trapping also has the potential to identify the presence and possibly abundance of pest species, which could be beneficial for pest control management.

Another technique which has yet to be trialled for monitoring banded rails in New Zealand is the eDNA detection method. International research suggests that this method can be used to successfully detect elusive and rare species in the environment, however challenges involve the requirement of a highly species-specific PCR assay which may take time to develop, and also specialised laboratory equipment (Neice & Mcrae, 2021).

In conclusion, the review has highlighted the need for a robust, long-term monitoring programme for New Zealand banded rails to effectively conserve this cryptic species. Based on the results of this review, trialling new techniques such as camera trapping, acoustic sensors and eDNA for the monitoring of New Zealand banded rails is highly recommended. However, the unique habitat of some populations of banded rail may require modifications to these techniques to ensure their feasibility and reliability for long-term monitoring. Additionally, interim sampling techniques such as call counts with the use of call-playback and footprint surveys should continue to be used for monitoring and inventorying banded rails. It is also crucial to refine the reliability and efficacy of call-playback surveys for use on New Zealand banded rails, to ensure the accuracy of population estimates and inform effective conservation management strategies. Overall, the implementation of a comprehensive, multi-method monitoring program will be essential for the continued survival and recovery of banded rails in New Zealand.

1.3 THESIS OVERVIEW

1.3.1 Thesis Aims and Objectives

Based on the knowledge gaps identified in the literature review, the central themes of my thesis are to determine the most effective monitoring methodology for confirming presence or absence and long-term monitoring of banded rails. Additionally, I aim to investigate which methodology is appropriate for monitoring banded rails in mangrove habitat, as these birds are often inconspicuous and difficult to detect.

The current literature on monitoring banded rails in New Zealand is limited, and my thesis aims to build on it by evaluating and comparing the effectiveness of various monitoring methods. Specifically, my thesis investigates the applicability and reliability of three monitoring techniques: footprint surveys, camera traps, and call-playback surveys. I examined each of these methods in individual chapters, allowing for a comprehensive analysis of their strengths and weaknesses. The findings of this research will improve the accuracy and precision of monitoring banded rails in New Zealand and potentially elsewhere, contributing to their conservation and management.

In **Chapter 2**, the effectiveness of footprint surveys will be investigated. This will involve assessing the accuracy and precision of footprint surveys for monitoring banded rail populations in New Zealand, as well as identifying the most effective sampling designs for footprint surveys. The findings from this chapter will provide insights into the optimal use of footprint surveys for banded rail monitoring.

Chapter 3 will focus on evaluating the use of camera traps for monitoring banded rails. This will involve investigating the effectiveness of camera traps in detecting banded rails and their behaviour in mangrove habitat, as well as assessing the feasibility of using camera traps as a long-term monitoring tool for banded rails. The findings from this chapter will provide guidance on the use of camera traps for monitoring banded rails in New Zealand.

In **Chapter 4,** the efficacy of call-playback surveys will be evaluated. This chapter aims to compare the effectiveness of different call-playback methods and identify the most effective method for monitoring banded rails in New Zealand. The findings from this chapter will provide insights into the use of call-playback surveys for banded rail monitoring.

In **Chapter 5**, I compare monitoring methodologies and discuss the general conclusions and the implications of the results for future research.

1.3.2 The Rail Trail Project

The Upper Waitematā Ecology Network (UWEN) is a coalition of community groups and organizations committed to preserving the local ecology of the upper Waitematā Harbour, Auckland, New Zealand. The UWEN initiated the Rail Trail Project, a strategic plan that aims to eliminate animal pests within the Upper Harbour local board area and its surroundings, to restore the mauri to the coast, and create an environment where the Moho Pererū (banded rail) can thrive. As a key indicator species, a major objective of the project is to understand the birdlife in the target area and track the population trends of banded rails in the area.

To achieve this goal, the UWEN needed to identify the most reliable way to inventory banded rails and monitor their populations in the local environment. The Rail Trail Project provided the groundwork for the research undertaken in this thesis, as well as the study location. This thesis aims to build upon the Rail Trail Project's objectives by investigating the efficacy of various monitoring techniques, such as footprint surveys, camera traps, and call-playback surveys, to monitor banded rails in mangrove habitat. The findings of this research will enhance the accuracy and precision of banded rail monitoring in New Zealand and contribute to the conservation and management of the species.

1.3.3 Study Location and Sites

The upper Waitematā Harbour, located west of Auckland city, New Zealand, encompasses approximately 120 km of coastline comprising various habitat types, including extensive strips of mangrove forests, estuarine mudflats, coastal forests, pasture, small wetland patches, and residential properties. Intertidal coastal vegetation is primarily dominated by mangroves, which provide potential foraging habitat for banded rails. However, not all parts of the coastline are easily accessible by foot for monitoring purposes.

Given the logistical constraints in accessing many coastal areas, 20 survey sites were selected around the upper Waitematā Harbour to represent the best coverage of a range of banded rail habitats and requirements (Figure 1.1). Sites were chosen based on several factors, including ease of access by foot, the presence of preferred habitat (salt marsh roosting habitat and mangrove forest), freshwater input, and banded rail sightings by local residents and community group members.

Freshwater presence was an important criterion in site selection because banded rails require access to both saltwater and freshwater environments (Elliot, 1983). Salt marsh and mangrove habitats were selected as preferred habitats for roosting and foraging by banded rails. The specific characteristics of the salt marsh and mangrove habitats that were important for banded rails included the presence of tidal inundation, dense vegetation cover, and protection from predators.

Some survey sites have a combination of salt marsh habitat, mangrove habitat, and freshwater input, while others lack salt marsh vegetation or freshwater input (Table 1.2). Local residents have reported banded rail sightings in areas with no salt marsh habitat or freshwater, indicating that survey sites must include various habitat types and characteristics. There have also been observations of potential roosting by banded rail in the mangrove canopy, which may suggest that non-breeding birds could use mangrove habitats that are not adjacent to salt marsh habitats (Blayney, 2017).

Overall, the 20 survey sites selected provide a representative sample of banded rail habitats in the Upper Waitematā Harbour and will facilitate the investigation of their distribution and habitat requirements in this region .

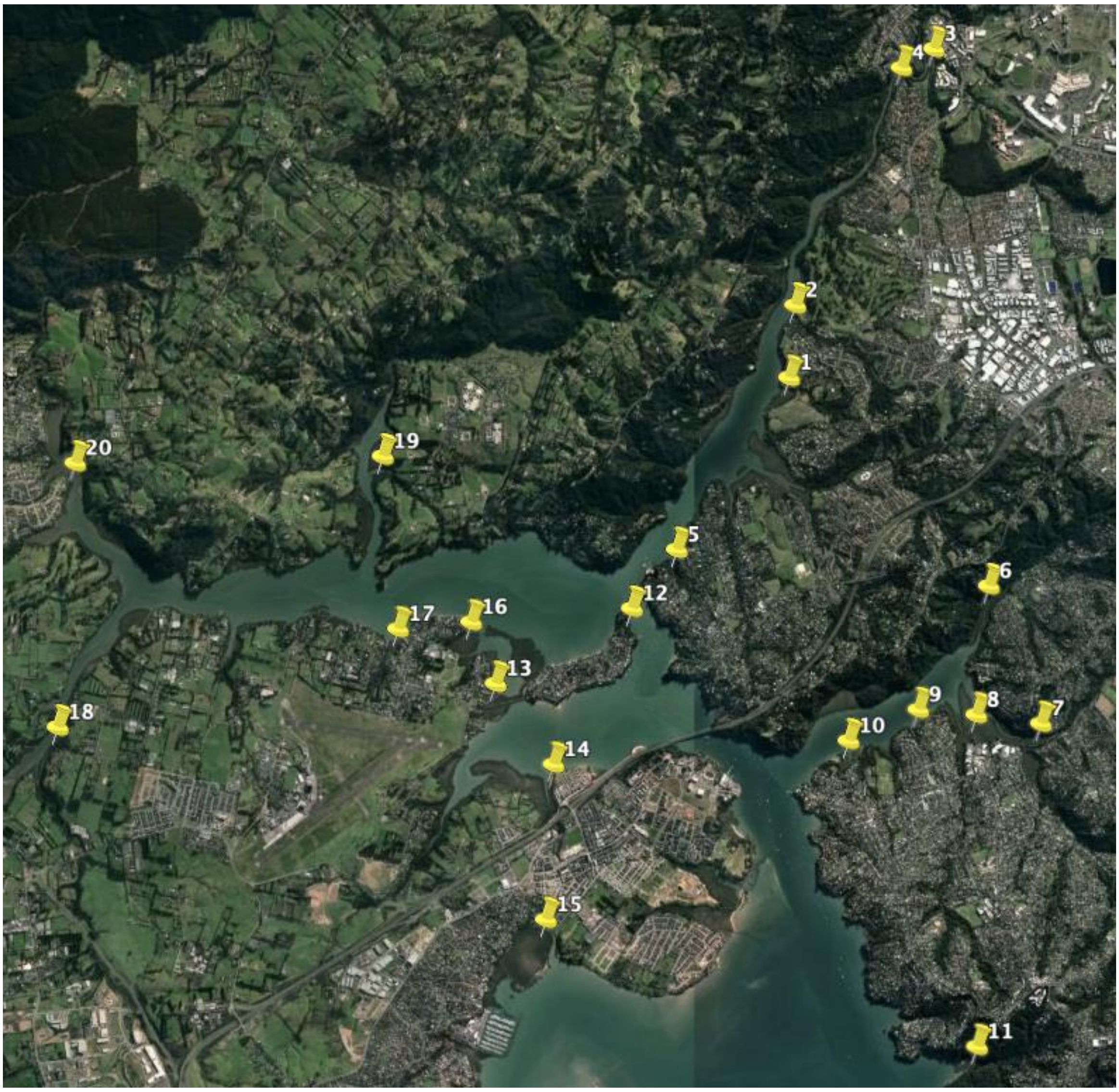

Figure 1.1: Map showing the location and number of the sites selected for testing banded rail monitoring techniques in the upper Waitematā Harbour, Auckland, New Zealand. Image from Google Earth, September 2022.

Table 1.2: Characteristics and habitat features of selected monitoring sites for banded rails in the upper Waitematā Harbour, Auckland, New Zealand.

Site no.	Site Name	S	E	Habitat description	Saltmarsh area (m^2)	Mangrove area (m^2)	Fresh water input
1	Albany Cemetery	36.7554881	174.6778444	Small margin of salt marsh and low mangroves with a small freshwater pond separated by a causeway	96.4	28,577	Yes
2	Wharepapa Reserve	36.7493399	174.6784279	Very small patch of salt marsh and mangroves with large coastal trees adjacent to a reserve	81.5	37,829	Yes
3	The Landing A	36.7270879	174.6933671	Small salt marsh wetland adjacent to narrow strip of mangroves. Public walking track and reserve close by	334	688	Yes
4	The Landing B	36.7287897	174.6898659	Small salt marsh wetland adjacent to narrow strip of mangroves. Public walking track and reserve close by	304	7,732	Yes
5	Oratau Place	36.7705679	174.6658973	Scattered patches of salt marsh against bush with large coastal Pohutakawa and multiple freshwater inputs	10.7	12,793	Yes
6	Kereru Grove	36.7734947	174.6992576	Raupo swampland and salt marsh against bush opening out into small clearing and extensive mangrove forest	645	78,045	Yes
7	Kaipatiki Road	36.7854025	174.7053127	Bush against extensive dense mangrove forest without salt marsh or freshwater input	0	43,696	No
8	Kahika Point Reserve	36.7847629	174.6981525	Extensive and dense mangrove forest with no salt marsh or freshwater input	0	170,345	No
9	Lancaster Road	36.7844374	174.6919224	Small mangrove forest against bush and residential properties. A freshwater stream runs through the middle	0	3,140	Yes
10	Tui Park	36.7867034	174.6844562	Young mangroves adjacent a small sandy beach with no salt marsh or freshwater input	0	30,179	No
11	Kauri Point Domain	36.8131984	174.6980302	Bush against large wetland habitat, raupo swamp areas, freshwater inputs, small mangrove forest. Busy public walking track	9,413	11,591	Yes
12	Herald Island	36.7755161	174.6609359	Small area of salt marsh against bush and young and mature mangroves	174	6,373	No
13	Kingsway Road	36.7821461	174.6460195	Small margin of salt marsh against residential property mangroves and large mudflats. A causeway separates the mangrove forest	56	114,662	No
14	Summerset Village	36.7887943	174.6524987	Very small patch of salt marsh with freshwater input and extensive mangrove forest and large mudflats	42.5	202,744	Yes

15	Limeburners Bay	36.8028938	174.6508156	Extensive dense mangrove forest with no salt marsh or freshwater input	0	264,848	No
16	Pohutakawa Road	36.7763953	174.6440081	Extensive young mangrove forest against residential property with small patch of salt marsh	22.9	51,092	No
17	Whenuapai Village Hall	36.7772931	174.6357416	Bush against small margin of salt marsh and mangroves with freshwater input	18.6	8,819	Yes
18	Dale Road	36.7782209	174.6180963	Scattered salt marsh against a strip of bush and old mangroves	54.9	61314	No
19	Sanders Reserve	36.7622278	174.6345352	Very small patch of salt marsh against bush and a large reserve with mangroves and no freshwater input	19.6	73,786	No
20	Riverhead Point Drive	36.7627379	174.6005969	Mature mangrove strip with no salt marsh or freshwater input	0	38,558	No

1.3.4 Research Contribution

This thesis significantly contributes to the scientific understanding of conserving cryptic wetland bird species, with a particular focus on banded rail populations in New Zealand. The study tested three monitoring techniques: footprint surveys, camera trapping, and call-playback surveys.

This thesis provides a comprehensive evaluation of the effectiveness of these techniques, which can inform the development of more efficient monitoring protocols for other cryptic wetland bird species. This research provides valuable insights into the factors affecting banded rail population dynamics, including their habitat preferences and distribution. The findings also contribute to the understanding of keystone species like the banded rail and their role in wetland ecosystem functioning.

Practically, this research informs the development of conservation management plans and provides crucial information to stakeholders, including conservation managers, policy-makers, and local communities. The study promotes the conservation of wetland ecosystems, supporting sustainable economic development and protecting cultural heritage. Overall, this thesis is a significant contribution to the scientific understanding of conserving cryptic wetland bird species, providing a foundation for future research in this field.

CHAPTER 2

Testing the Efficacy of Footprint Surveys for Monitoring Banded Rails in Mangrove Habitats

2.1 INTRODUCTION

Monitoring cryptic, rare, or low-density species is vital for effective conservation management (Buckland et al., 2019). However, detecting such species can be challenging using traditional monitoring methods (McClintock et al., 2010). Non-invasive monitoring techniques like footprint tracking have gained popularity due to their effectiveness in detecting elusive species (Russell et al., 2009). Footprint surveys have been used to detect banded rails (*Rallus philippensis assimilis*) in New Zealand, where these birds primarily inhabit mangrove forests that make other monitoring methods difficult to apply (Beauchamp, 2015; Botha, 2010; Elliott, 1987). While footprint surveys offer a cost-effective and non-invasive means of assessing banded rail presence, they are labour-intensive and can be influenced by tide state, weather events, and bird activity levels (Beauchamp, 2015; Elliott, 1987). Therefore, these limitations must be considered when designing an appropriate sampling regime for banded rails.

Banded rails have relatively distinctive footprints, which are approximately 36-47 mm long and symmetrical (Elliott, 1987). The use of coastal mangrove forests as critical foraging habitat makes upper North Island banded rail populations unique, unlike South Island populations that lack this habitat type. The silt substrate in mangrove habitats can hold prints well, making it an ideal habitat to test footprint surveys as a monitoring method. Footprint surveys can be conducted at any time of the year, as the presence of footprints is independent of the breeding season. However, rain and tidal movement can obliterate footprints, and surveys should be conducted 1-2 hours after low tide to ensure the substrate is visible.

2.1.1 Study Objectives and Conservation Significance

Currently, there is limited research on the use of footprint surveys for detecting the presence or absence of banded rails, and more effective monitoring tools are needed. This chapter aims to fill this gap by assessing the efficacy of footprint surveys for monitoring banded rails in the upper Waitematā Harbour and obtaining inventory information on their current presence/absence. The research in this chapter also aims to identify any environmental and biotic factors that significantly influence banded rail footprint frequency to better understand the ecological factors that impact banded rail distribution in the study area. Lastly, this study aims to compare the data gathered through footprint surveys with that obtained from other survey methods such as camera trapping and call-playback surveys (Chapters 3 and 4). The results will aid in identifying important banded rail habitats and support conservation management decisions, including the allocation of pest control measures and mangrove management efforts.

The conservation significance of this study lies in its potential to inform future predator control measures and identify critical areas of banded rail habitat that may require enhanced protection. By conducting footprint surveys, the data collected can contribute to a better understanding of the ecology and population dynamics of the banded rail in this region, aiding in the development of effective conservation strategies. Additionally, this study represents the first comprehensive inventory of banded rail presence and absence in the upper Waitematā Harbour area, making it an important contribution to the existing literature on banded rail conservation.

2.2 METHODS

2.2.1 Animal Ethics Considerations

This study did not involve any invasive or harmful procedures to the study species or their habitat, and therefore did not require an ethics permit. To minimize disturbance to banded rail populations, all surveys were conducted during daylight hours and with minimal disturbance to the habitat. Additionally, all researchers were trained in appropriate survey techniques and adhered to strict protocols to ensure that the welfare of the animals was not compromised.

2.2.2 Pilot Study

Prior to conducting the main study, a pilot study was carried out on April 26th, 2022 in a large saltmarsh wetland area with adjoining mangrove forest located in the Mangawhai Harbour, Northland, New Zealand (Figure 2.1). The site was selected based on the confirmation of banded rail presence by another Massey University student who tracked them using GPS technology during their research. The pilot study aimed to test the methodology for the footprint surveys that were planned for the main study. The outcome revealed that the planned methodology was appropriate and effective in detecting banded rail footprints in high density, which was expected. Additionally, the pilot study provided valuable experience in navigating subtidal mangrove forests using GPS.

Figure 2.1: Map of the pilot study site in Mangawhai Harbour, Northland, New Zealand, where the effectiveness of the footprint survey methodology for detecting banded rails was tested. The map highlights the boundary of the study area (red box), water bodies, roads, and topography. Image obtained from Google Earth, October 2022.

2.2.3 Main Study Sites

Over a period spanning from May 3 to August 14, 2022, I conducted 40 footprint surveys at 20 sites located in the upper Waitematā Harbour, Auckland, New Zealand (Figure 2.2). All 20 sites outlined in chapter one were included in the footprint survey research conducted in this chapter (see Table 1.1 and Figure 1.2 in Chapter One). All sites were accessible by foot, and since footprint surveys require limited equipment and can be conducted during daylight hours, it was possible to include all sites in the study. These sites cover a range of habitat types around the upper Waitemata Harbour coastline and are suitable for carrying out footprint surveys. This comprehensive approach provides a robust dataset for assessing the presence and absence of banded rails across the study area.

Figure 2.2: Study location for footprint surveys in the upper Waitematā Harbour, Auckland, New Zealand. The map shows key features such as the study area boundary (red box), water bodies and topography. Image obtained from Google Earth, October 2022.

2.2.4 Temperature and Weather Conditions

During the survey period, the recorded temperatures ranged between 6 and 21 ºC. The wind speed varied between 5 and 35 km/h at the time of the survey. The surveys were conducted in both sunny and overcast conditions and were not carried out during or after rainfall.

2.2.5 Using Banded Rail Ecology to Select Plot Locations

Based on the available knowledge of banded rail habitat use and ecology in New Zealand, specific plots were identified at each of the 20 study sites to conduct footprint surveys. This was done by drawing on previous studies and existing knowledge of banded rail ecology to select suitable areas where the birds were likely to be present in each survey location. These plots were carefully selected to ensure adequate coverage of the different habitat types found around the upper Waitemata Harbour coastline. By using this approach, the research aimed to increase the likelihood of detecting banded rails and collect accurate data on their presence in the study area.

Banded rail behaviour is influenced by their life history and diet requirements, which in turn affect their movement patterns and the distribution of their footprints (Botha, 2010). Banded rails have been found to prefer foraging in mangrove habitats over salt marsh habitats due to the former's protection from aerial predators (Botha, 2010). Additionally, banded rail activity is highest in salt marsh and mangrove habitats that are frequently inundated by the tide, which is likely due to the greater abundance of food in these areas (Botha, 2010; Elliott, 1987).

Based on this information, search efforts during the footprint surveys were focused on areas where banded rail footprints were more likely to be present. These areas included mangrove habitats adjacent to salt marshes (roosting/nesting habitat), up to 300m seaward from the salt marsh habitat (if present) and within 1 m from the mangrove canopy edge out onto the open mudflat, and areas where channels were directly linked to a freshwater source, such as a river or stream. At sites where salt marsh habitat was absent, searches focused on areas with mangrove cover and near freshwater channels (if present). The coastal edge was also considered during searches at these sites, as some sites lacking salt marsh may provide other habitat features that banded rails utilize, such as terrestrial grasses and shrubs or large trees on the shoreline that may provide extra foraging cover.

2.2.6 Data Collection

In this study, a total of 60 plots, consisting of three 10 m x 10 m (100m2) plots at each of the 20 survey sites, were established and marked with coordinates on Google Maps. I systematically searched plots for banded rail and predator footprints (Figure 2.3). The location of each plot was carefully selected based on the site's topography and banded rail habitat use, as discussed earlier. To facilitate systematic and comprehensive data collection, each plot was further subdivided into five quadrats measuring 1 m x 1 m, placed at the four corners and one at the centre of the plot (Figure 2.4). Additionally, two transects were marked on Google Maps to facilitate the movement of surveyors between plots. It is important to note that the plot outlines in Figure 2.4 are only indicative, and the actual GPS coordinates and straight lines were marked while in the field using a measuring tape to ensure accurate measurements.

Figure 2.3: Photographs showing banded rail footprints among mangrove pneumatophores (Left), and predator footprints alongside banded rail footprints (Right), in the upper Waitematā Harbour, June 2022. Photos by I. Mallinder-Capamagian, June 2022.

Figure 2.4: A satellite image of the Kereru Grove survey site depicting the layout of plots and quadrats. The starting points for each survey are marked with tags on the map, while the plot outlines are shown in red, blue, and yellow for plots one, two, and three, respectively. The white lines represent the transects between the plots. Image obtained from Google Maps, October 2022.

Prior to each survey, I carefully documented the weather and tidal conditions (Appendix A). Since tidal movement affects banded rail habitat use and footprint accumulation, surveys were initiated within an hour after low tide to ensure that footprints had accumulated and that the substrate was not too flooded. To avoid the impact of rain on footprints and substrate quality, no surveys were conducted following recent rainfall.

To collect footprint data, I used a systematic approach to search each plot (Figure 2.5), recording the number and direction of footprints. Footprint direction was categorized as either 1 (towards the sea), 2 (towards the land), or 3 (other). Starting from the first corner of plot one, I marked out a quadrat using rope and wooden sticks and recorded the number and direction of any banded rail footprints. I also evaluated the quality of the substrate within each plot. According to a Massey University PhD student's unpublished research, the substrate in mangrove habitats was graded as 0 for poor, 1 for fair, or 2 for excellent (unpublished data). Then, I walked in a straight line at a consistent pace to the next corner of the plot, recording the location (coordinates), number, and direction of footprints, and repeated the quadrat search at the next corner of the plot. I continued this process until I had searched all four corners of the plot and returned to the starting point. Finally, I searched the interior of the plot, including the fifth quadrat in the centre, using a systematic approach (walking up and down the plot).

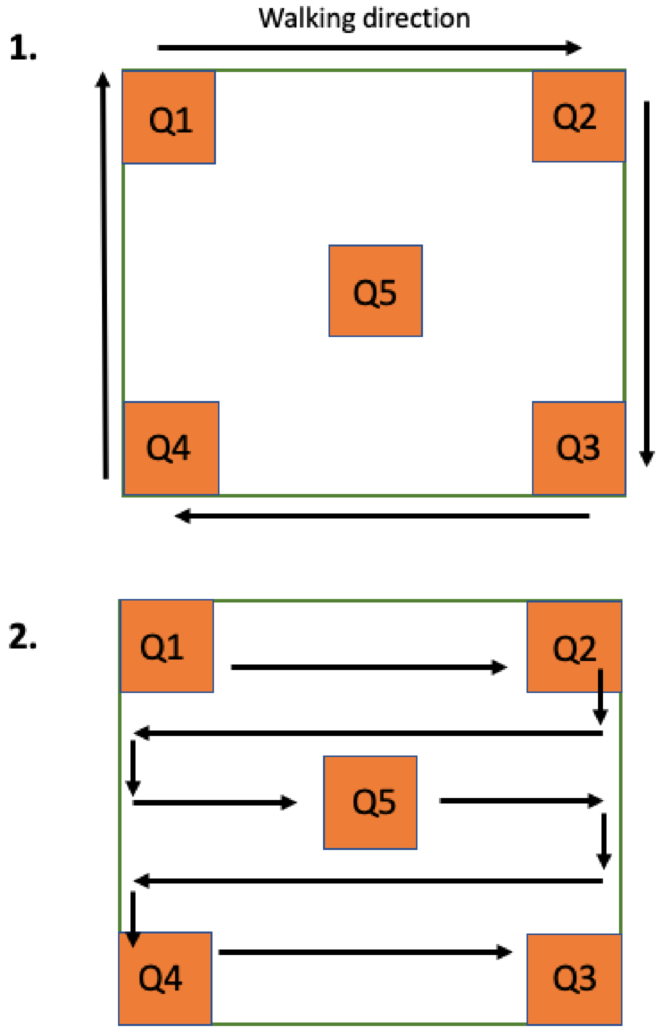

Figure 2.5: Diagram illustrating the systematic search strategy employed to detect footprints during the survey. Black arrows indicate walking direction. 1) Quadrats 1 to 4 were searched using a specific walking direction, and 2) The inside of the plot, including quadrat 5, was systematically searched using a consistent approach.

After completing the search of the first plot, I walked along the first transect to reach the location of the second plot, recording the location and number of any footprints found. I repeated the plot search described above in plots 2 and 3. To minimize the risk of bias, the maximum search time across repeated surveys and sites was standardized, and each site was searched for a maximum time of 1 hour.

To minimize the potential of obtaining a false absence of banded rail, two surveys were conducted at each site within a seven-day period. This approach aligns with the findings of Williams (2016) who, when designing a monitoring protocol for Australasian bitterns, a cryptic marsh bird, determined that increased survey effort reduced the likelihood of not detecting a species and that two or three visits to a site were necessary before concluding that a species was absent from a sampling area.

2.2.7 Statistical Analysis

To evaluate the relationship between the frequency of banded rail footprints and various environmental and biotic factors, I conducted a statistical analysis on the footprint count data collected from 40 surveys. Generalized Linear Models (GLMs) with Poisson distributions were fitted in R Version 1.4.1717 (R Core Team, 2021) to investigate the significance of each explanatory variable. The factors tested for their potential effect on footprint frequency included the size of mangrove and salt marsh habitats, the presence of freshwater, substrate quality, predator presence, and connectivity of the mangrove forest to other patches.

Predator presence was assessed through the footprint data collected in this study. Specifically, observations of predator footprints were recorded during the surveys, contributing to the assessment of this variable. To assess connectivity between mangrove forest patches, a visual examination using Google Earth was employed, identifying potential connections based on the observed proximity and visual corridors between patches. Although this approach lacks the precision of formal GIS analysis, it provided qualitative insights into the spatial arrangement, influencing the subsequent consideration of connectivity in the statistical analysis of banded rail footprint frequency.

To account for potential variation in footprint frequency across sites, I included site as a random effect in a mixed-effects model. The mixed-effects model was fitted using the 'lme4' package in R (Bates et al., 2015). Specifically, I used the 'glmer' function to fit a generalized linear mixed-effects model, with a binomial distribution and logit link function. The model formula included the fixed effect of treatment, as well as the random effect of site. The resulting model estimates the effect of treatment while accounting for any variation in the number of samples per site. The 'coef' function was then used to extract the estimated coefficients and their standard errors, which were used to generate a forest plot to visualize the results.

To determine the best model fit and the significance of each explanatory variable, I examined each model's Akaike information criterion (AIC) and p values. This approach allowed me to identify factors that significantly influenced banded rail footprint frequency and better understand the ecological factors that impact the species' distribution in the study area.

2.3 RESULTS

2.3.1 Sampling Effort

I spent a total of 52 hours conducting surveys, including 40 hours in the field and 12 hours traveling to and from survey locations. Some sites required a strenuous trek through dense coastal forests and steep terrain, while others were challenging to navigate due to boggy substrate in the coastal mangrove habitats. Despite these challenges, I was able to complete the surveys using standard field equipment, recording data on field sheets.

2.3.2 Footprint Detection

Banded rail footprints were detected at 15 out of the 20 sites, with the absence of any footprints at five sites during either of the two surveys. Among the sites with banded rail footprints, the highest frequency of prints was recorded at Summerset Village (Figure 2.6), with a total of 381 banded rail footprints detected over the course of the two surveys (average = 190.5). Significant intra-site variation between surveys is evident at most sites. For example, at Landing B site, notable variation was observed between surveys, with no footprints detected during the first survey, contrasting with the subsequent survey where 36 footprints were counted (Table 2.1).

Banded rail were not detected at 5 sites, those sites being; Kahika Point, Tui Park, Herald Island, Kingsway Road and Dale Road. In addition, predator footprints were identified at 35% of the surveyed sites, amounting to a total of seven sites. The distribution of these findings is presented in Table 2.1 for reference. The footprint density ranking for each site was based on the average number of footprints recorded over two surveys. The density of footprints were classified into four categories: None (no footprints observed), Low (1-20), Medium (21-99), or High (100+), with higher values indicating higher densities.

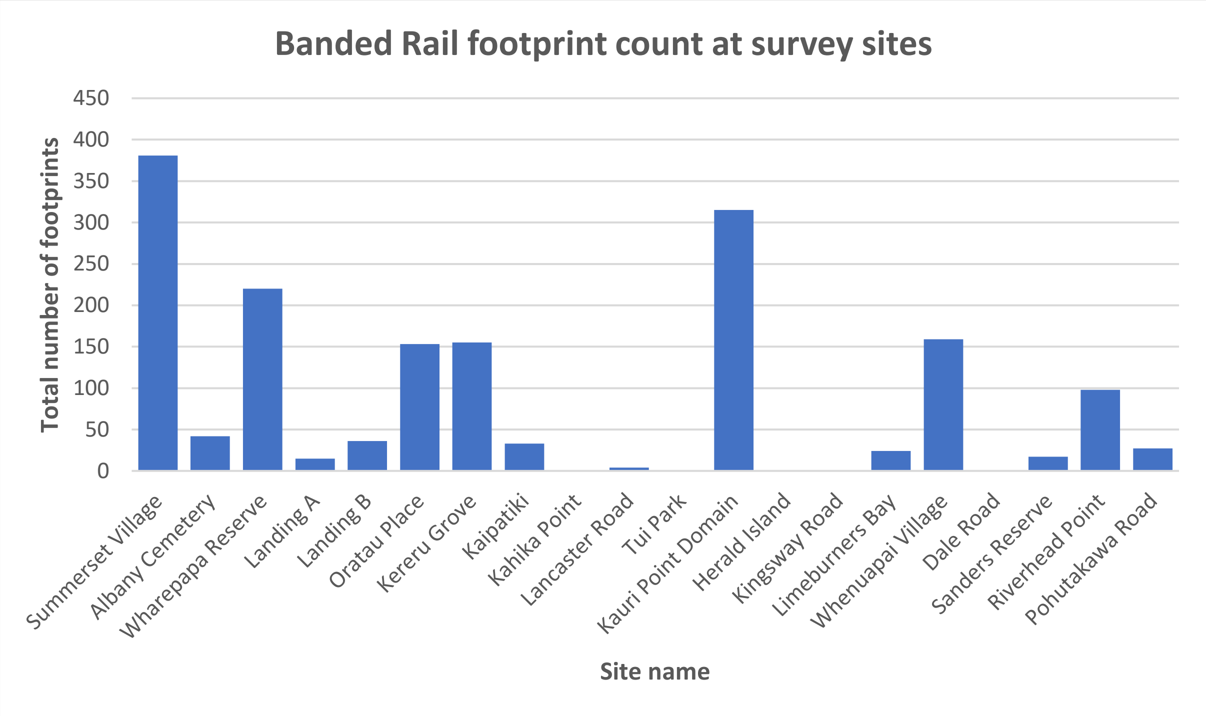

Figure 2.6: Total number of footprints recorded at each survey site. The number of footprints recorded over two surveys is shown on the y-axis, and the survey sites are listed on the x-axis.

Table 2.1: Banded rail footprint counts and density rankings (from highest to lowest) at sites in the upper Waitematā Harbour. This table shows the results of surveys conducted at 20 survey sites, with footprints classified into four categories based on the average number of footprints over two surveys.

Site name	**Survey 1**	**Survey 2**	**Total footprints**	**Average footprints per survey**	**Footprint density ranking**
Summerset Village	194	187	381	190.5	High
Kauri Point Domain	193	122	315	157.5	High
Wharepapa Reserve	154	66	220	110	High
Kereru Grove	64	91	155	77.5	Medium
Oratau Place	17	136	153	76.5	Medium
Riverhead Point	57	41	98	49	Medium
Whenuapai Village	64	95	159	29.5	Medium
Albany Cemetery	20	22	42	21	Low
Landing B	0	36	36	18	Low
Kaipatiki	23	10	33	16.5	Low
Pohutakawa Road	7	20	27	13.5	Low
Limeburners Bay	9	15	24	12	Low
Sanders Reserve	9	8	17	8.5	Low
Landing A	0	15	15	7.5	Low
Lancaster Road	4	0	4	2	Low
Kahika Point	0	0	0	0	None
Tui Park	0	0	0	0	None
Herald Island	0	0	0	0	None
Kingsway Road	0	0	0	0	None
Dale Road	0	0	0	0	None

2.3.3 Abiotic and Biotic Factors Influencing Footprint Frequency

The initial model consisted of nine predictor variables, including vegetation type, vegetation height, mangrove size, salt marsh size, freshwater presence, predator presence, substrate quality, habitat shape, and mangrove isolation, with Site as a random effect.

A stepwise backward elimination procedure was used to reduce the model complexity and obtain a parsimonious model with the best fit to the data based on the Akaike information criterion (AIC). The final model retained eight predictor variables, which were significant factors influencing the frequency of banded rail footprints ($P < 0.05$). The strongest factors were mangrove forest size, freshwater presence, and substrate quality, ($P < 0.001$). The model indicated that banded rail footprints were most abundant in habitats with larger areas of mangrove forest, the presence of freshwater, and better substrate quality. The final model had a deviance of 2332.2 on 701 degrees of freedom and an AIC of 3293.5 (Table 2.2), demonstrating a significant improvement over the null model. All the predictor variables in the final model, except for the 'Predators' variable, had statistically significant p-values ($P = 0.158$).

Table 2.2: Results of multiple regression analysis showing the estimates, standard errors, z values, and p values for predictor variables and their effect on the response variable.

Predictor Variables	**Estimate**	**Std. Error**	**Z Value**	**P Value**
(Intercept)	-6.463	0.364	-17.780	< 2e-16 ***
Mangrove size	0.0000201	0.0000025	8.093	5.18e-16 ***
Saltmarsh size	0.0001317	0.000037	3.563	0.000367 ***
Mangrove isolation (isolated)	1.069	0.193	5.526	3.27e-08 ***
Substrate	60.687	0.043	16.141	< 2e-16 ***
Predators	-0.1295	0.09176	-1.411	0.15813
Freshwater	2.231	0.1722	12.952	< 2e-16 ***
Habitat shape (narrow)	1.005	0.2051	4.899	9.64e-07 ***
Habitat shape (oval)	-4.582	0.5771	-7.939	2.04e-15 ***
Habitat shape (triangle)	0.8633	0.3274	2.637	0.008367 **
Habitat shape (wide)	-1.782	0.4439	-4.014	5.97e-05 ***
Vegetation height	0.5597	0.07001	7.995	1.130e-15 ***
Vegetation type (medium mangroves)	0.9209	0.162	5.684	1.31e-08 ***
Vegetation type (small mangroves)	2.254	0.2186	10.311	< 2e-16 ***
Random effects:				
Site (Intercept)	0.245	0.057		

A comparison of the coefficients and their confidence intervals for each predictor variable is presented in Figure 2.7 to provide further insight into their impact on the frequency of banded rail footprints. Figure 2.7 highlights the positive and negative relationships between the predictors and the outcome variable. The error bars indicate the uncertainty associated with each coefficient estimate. The most significant relationships were mangrove forest size and the availability of freshwater.

Moreover, the Poisson distribution was found to be an appropriate fit for the data, compared to the negative binomial GLM, which allows for overdispersion. The Poisson model better fit the data, with a lower AIC value (AIC = 184.2) than the negative binomial model (AIC = 196.7).

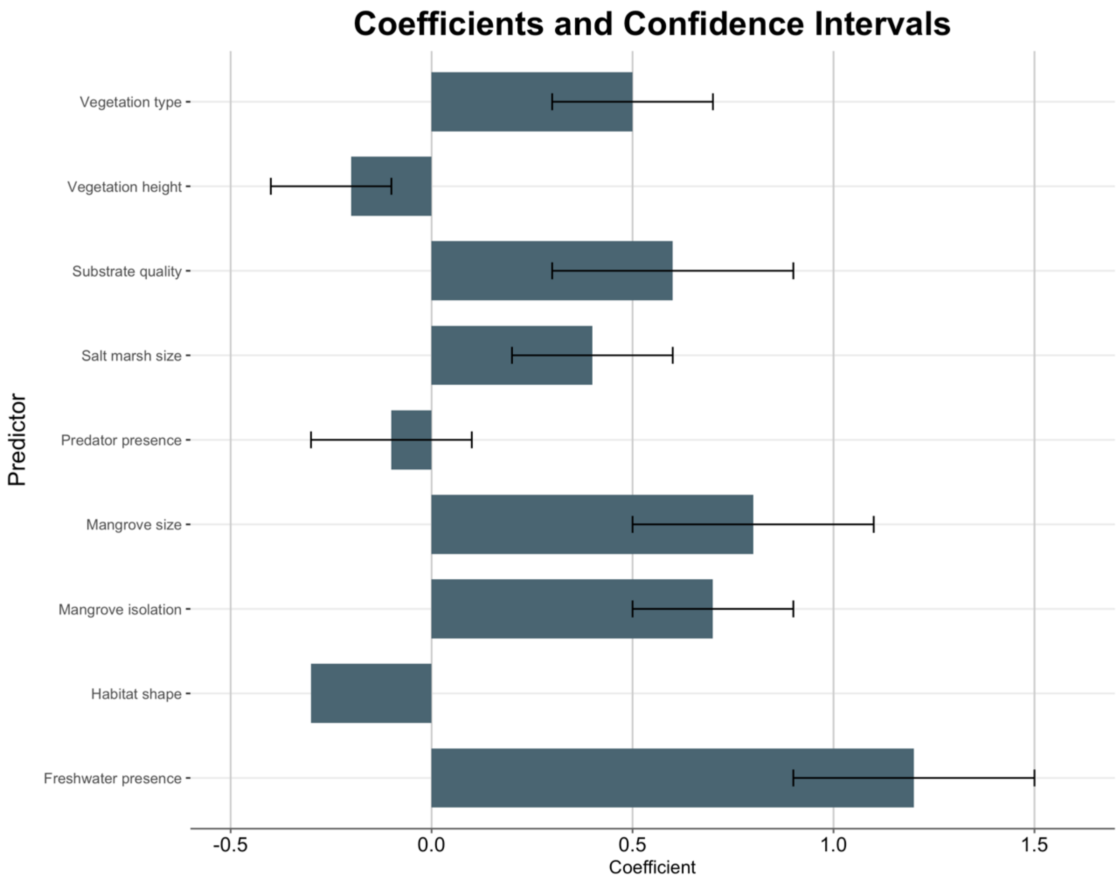

Figure 2.7: Bar chart showing the coefficients and confidence intervals of predictors in a generalized linear model (GLM) with a Poisson distribution model. The coefficients are displayed on the horizontal axis and the predictors on the vertical axis. The error bars indicate the uncertainty associated with each coefficient estimate.

The final mixed-effects model with site as a random effect, included predictor variables of Mangrove size, Saltmarsh size, Freshwater presence, Substrate quality, and Mangrove isolation (Table 2.3). The model showed a good fit (AIC = 3108.1) and explained a significant proportion of the variation in the response variable (deviance = 3094.1, df.resid = 709).

Table 2.3: The estimated coefficients and significance levels for fixed effects and variance for random effects from the mixed effects model.

Predictor Variables	**Estimate**	**Std. Error**	**Z value**	**P value**
(Intercept)	-2.48483	0.67916	-3.659	0.000254 ***
Mangrove size (rescaled)	0.19453	0.44525	0.437	0.662181
Saltmarsh size (rescaled)	0.55823	0.47746	1.169	0.242335
Freshwater	1.57150	0.47212	3.329	0.000873 ***
Substrate	0.60900	0.04240	14.364	< 2e-16 ***
Mangrove isolation (isolated)	0.03113	0.91196	0.034	0.972771
Random effects:				
Site (Intercept)	3.289	1.814		

The results indicated that the presence of freshwater was a significant predictor of banded rail footprint frequency, with a coefficient estimate of 1.57 ($P = 0.000873$). This suggests that banded rail footprints are more likely to be found in areas where freshwater is present. Additionally, substrate quality was also found to be a significant predictor of banded rail footprint frequency, with a coefficient estimate of 0.60 ($P < 0.001$).

Mangrove size and salt marsh size were not found to be significant predictors of banded rail footprint frequency, with coefficient estimates of 0.19 ($P = 0.662181$) and 0.55 ($P = 0.242335$), respectively. Mangrove isolation was also not found to be a significant predictor of banded rail footprint frequency, with a coefficient estimate of 0.03 ($P = 0.972771$).

2.3.4 Footprint Direction

I found that footprints were most frequently directed towards land (55% of recorded footprints), followed by footprints directed towards the sea (32%), and footprints with other directions (13%).

2.4 DISCUSSION

Developing non-invasive monitoring techniques for cryptic species, such as the banded rail, is fundamental for conservation management. This study indicates that footprint surveys may be a reliable way to gather inventory information about the presence/absence of banded rails and could be used over the long term for monitoring trends and changes over time.

2.4.1 Banded Rail Detection

From the 20 sites I surveyed in the upper Waitematā Harbour, banded rails were detected at 15 sites but not at the remaining five sites. It is important to note that the absence of banded rails at these five sites does not necessarily indicate a true absence of the species. Ecological systems are dynamic, and factors such as low population density, seasonal variations, or habitat preferences may contribute to the variability in detection. This highlights the importance of conducting multiple surveys that span different time periods and habitats to better understand banded rail presence and distribution in the region. Intra-site variation in detection between the first and second surveys of each site also suggests potential temporal fluctuations in habitat use, emphasizing the importance of considering temporal dynamics in the interpretation of banded rail footprint frequency.

2.4.2 Factors Influencing Banded Rail Footprint Frequency

In this study, I analysed the factors influencing the frequency of banded rail footprints across 20 sites. The results indicated that the abundance of banded rail footprints was significantly associated with the presence of freshwater, the quality of the substrate, and the extent of mangrove forest in the habitat. Specifically, banded rail footprints were more commonly found in habitats with larger areas of mangrove forest, better substrate quality, and freshwater availability. These findings are consistent with previous studies that have reported the importance of mangrove forest habitats for the survival and persistence of banded rails (Sherley et al., 2019).

The results of this study were largely consistent with previous research on banded rail habitat preferences. Banded rails have been reported to have a metabolic requirement for freshwater, which may explain the significant association between freshwater presence and banded rail footprint abundance found in this study (Miskelly et al., 2019). Similarly, larger areas of mangrove forest may provide a more suitable habitat for banded rails, allowing for larger populations to exist (Sherley et al., 2019). The association between substrate quality and footprint frequency was also expected, as poor substrate quality, such as in flooded or debris-filled areas, may make it more difficult to observe banded rail footprints. These findings highlight the importance of understanding the specific habitat requirements of banded rails for effective conservation management.

2.4.3 Additional Insights

During the footprint surveys, I also recorded the presence of potential predators of banded rails, such as rats, mice, cats, and possums. Seven sites had rodent footprints detected, indicating the possible threat to banded rail populations in these areas. The absence of predators in the remaining sites may not necessarily mean that these habitats are predator-free, as the detection of predators is influenced by various factors such as survey duration and environmental conditions. Nevertheless, identifying predator presence can provide important information for banded rail conservation efforts. For example, this data could be used to prioritize areas for targeted pest control interventions by community groups or conservation organizations, as has been demonstrated in previous studies (Moorhouse et al., 2003).

The directional orientation of banded rail footprints collected during the surveys provided data on the potential movement patterns and behaviour of the birds. For example, a unidirectional movement towards the sea could indicate following of the outgoing tide during foraging. Alternatively, footprints going in all directions may suggest that the bird may have been foraging in the area. Previous studies have also used footprint direction to gain insights into bird behaviour, such as foraging strategies (van der Graaf et al., 2006). Results suggests that banded rails in my study area may be more likely to forage and move towards land. However, it is important to note that the direction of footprints does not necessarily correspond to the direction of movement or habitat use by the banded rails, and further research is needed to confirm these patterns.

2.4.4 Limitations

Footprint surveys are a valuable tool for monitoring the abundance and distribution of banded rails in wetland habitats, but they also have limitations. One of the main limitations is the potential for false absences, particularly if the population is small or the habitat being sampled is large. While the presence of the target species can usually be confirmed, it is difficult to confirm their absence with certainty. To mitigate this issue, increasing survey efforts and repeating surveys at least three times within a relatively short timeframe may be necessary (Blayney, 2017).

Another limitation to consider is whether footprint surveys can be used to estimate the population density of banded rails. While this study found that habitat factors influence the frequency of banded rail footprints, it is uncertain whether footprints can be used as a proxy for population density. Future studies could investigate the relationship between footprint frequency and population density to better understand the population dynamics of banded rails and how to manage them effectively. However, this issue is not unique to footprint surveys and is a common challenge in population monitoring studies (Hamer et al., 2015). Thus, further research is necessary to determine the usefulness of footprint surveys for estimating banded rail population density.

Additionally, time and weather restrictions and accessing sites can pose challenges for conducting surveys, especially in coastal mangrove forests. Seasonal variation in habitat use may also affect the accuracy of footprint surveys in detecting banded rails, particularly during moulting, nesting, and fledging stages (Doughty et al., 2018). Furthermore, it is unclear whether the results of this study can be generalized to other regions or other similar rail species. Thus, caution must be exercised when extrapolating the findings to other areas and species (Znidersic, 2019). Despite these limitations, footprint surveys remain an important tool for gathering long-term inventory data on banded rails and can inform conservation and management efforts in wetland and mangrove habitats.

2.4.5 Conclusions and Recommendations

This study has demonstrated the applicability of footprint surveys for use in mangrove habitats to detect banded rail presence. The results show that habitat factors, such as vegetation structure and freshwater presence, can influence the frequency of banded rail footprints and that this information can be used to gather inventory information and monitor trends over time. The purpose of this study was to assess the reliability of footprint surveys for monitoring the presence/absence of banded rails, and the results indicate that more data is needed before classing footprint surveys as a reliable tool for detecting banded rail presence/absence in mangrove habitats. Further research is needed to improve the effectiveness of footprint surveys for banded rail conservation. Future studies could investigate the reliability of footprint surveys over time and their sensitivity to population changes. Additionally, exploring the use of footprints as an indicator of density and incorporating footprint surveys with other monitoring methods could provide a more comprehensive understanding of banded rail ecology and behaviour.

In conclusion, footprint surveys are a valuable tool for monitoring banded rails in wetland habitats, but further research is needed to improve our understanding of their reliability and sensitivity to population changes. By addressing these research gaps, we can develop more effective conservation strategies to ensure the persistence of this important species.

2.4.6 Conservation Outcomes

The long-term benefits of the footprint surveys in this study go beyond just the data gathered for this specific research. By conducting footprint surveys consistently over time, this method can provide valuable inventory information on banded rail populations, including tracking their presence and absence at various sites. This information can be used to monitor population changes and assess the effectiveness of conservation efforts, such as predator control measures.

The insights gained from the models used in this study can inform and guide conservation efforts aimed at protecting and restoring mangrove and salt marsh habitats, which are critical to the survival of banded rails. Ultimately, the data collected through footprint surveys can contribute to the long-term conservation and management of wetland habitats, ensuring the persistence of banded rails and other important wildlife species.

CHAPTER 3

Evaluating Camera Trapping as an Effective Technique for Monitoring Banded Rails

3.1 INTRODUCTION

Effective monitoring techniques are critical for the conservation of wildlife populations, especially those that are rare, cryptic, or vulnerable to threats such as predation (Groombridge, 2011). Traditional monitoring methods often fail to provide accurate and comprehensive information about such species, necessitating the need for novel approaches. Camera traps, also known as autonomously triggered cameras, have emerged as a promising tool for monitoring wildlife populations (Kays et al., 2011). Although extensively used for mammalian species, their utility for avian research is relatively new and still being explored (O'Brien & Kinnaird, 2008).

Given the challenges associated with monitoring elusive and rare species, camera traps are become increasingly popular in wildlife research (Swinnen et al., 2019). The non-invasive nature of camera traps reduces the disturbance to wildlife, and the devices can operate continuously, providing comprehensive data on species activity patterns (Kays et al., 2011). In the context of avian research, camera traps have been extensively used for monitoring mammalian species, with their utility for avian research still being explored (O'Brien & Kinnaird, 2008). Recent studies have shown that camera traps can also effectively monitor avian populations, including wetland birds such as the banded rail (Znidersic, 2017; Buxton et al., 2018). By providing accurate information on species presence, distribution, and abundance, camera traps can play a vital role in conserving the banded rail and other avian species in wetland habitats.

The banded rail (*Hypotaenidia philippensis assimilis*), a small bird species that inhabits dense mangrove vegetation in the upper north island of New Zealand, is a challenging species to monitor using traditional techniques due to its secretive nature (Znidersic, 2017). However, new and effective monitoring techniques are essential given its conservation status and the lack of data on its population status, habitat use, and activity patterns (Robertson et al., 2021). Camera traps offer a non-invasive means of monitoring the banded rail population and gathering information on its behaviour and habitat use. Although the use of camera traps for monitoring wetland birds, including the banded rail, has been proposed in the past literature (Blayney, 2017), there is still a lack of research on the effectiveness and applicability of this monitoring technique for this species.

Although photographs from camera traps can confirm a species' presence and identity and provide insights into distribution, abundance, population dynamics, and behaviour (O’Brien & Kinnaird, 2008), camera trap surveys can be labour-intensive, particularly in terms of data management and specific constraints and limitations should be considered when designing an experiment. Such factors include camera placement and orientation, camera settings, temperature differentials, trigger and recovery time, and the animals' behavioural responses (Meek et al., 2015).

3.1.1 Study Objectives and Conservation Significance

This study aims to investigate the effectiveness of camera trapping as a monitoring tool for banded rails and has three specific objectives. Firstly, it seeks to assess the reliability and efficacy of camera trapping in capturing banded rail activity. Secondly, the use of camera trapping will enable comprehensive inventory data to be gathered regarding the presence or absence of banded rails in the study area. This study aims to investigate the environmental and biotic factors influencing banded rail captures, to help provide better understanding of banded rail distribution in the study area. Lastly, the study aims to compare the data gathered through camera trapping with that obtained from other survey methods such as footprint surveys (Chapter 2) and call-playback surveys (Chapter 4).

At present, the optimal method for monitoring banded rails is still unknown. This study aims to shed light on the effectiveness of camera trapping as a monitoring tool and its potential to supplement or supplant traditional survey techniques. Accomplishing these goals will increase our understanding of the applicability of camera traps for monitoring banded rails, while providing critical information on their population status and habitat usage in the upper Waitematā Harbour. This knowledge will be instrumental in guiding predator control measures and identifying crucial areas of banded rail habitat that require increased management and conservation efforts.

3.2 METHODS

3.2.1 Animal Ethics Considerations

Due to the non-invasive nature of this study and the minimal disturbance to the study species and their habitat, an ethics permit was not required. Precautions were taken during the camera trapping process to minimize any potential disturbance to the banded rail populations. Although some vegetation had to be removed to ensure optimal camera placement, this was kept to a minimum, and care was taken not to extensively modify the habitat. A quiet approach was employed while setting up the equipment, ensuring that the birds' natural behaviour was not disrupted.

3.2.2 Pilot Study

A pilot study was conducted on June 28, 2022, at the Summerset Village survey site, which was also included in the main study (Figure 3.1). This site was chosen based on previous confirmation of banded rail presence during footprint surveys in Chapter Two and regular observations by local residents. The purpose of the pilot study was to test the camera trapping methodology, including camera placement, height, and settings, and to determine survey duration and the frequency of SD card swaps and battery changes. The same methods as those described in the main study were used, with the addition of video settings for the main study.

Camera settings, height and angle, were tested during the pilot study by walking past the camera to imitate the movement of banded rails. Images were reviewed during camera deployment to check the optimal focal distance and to check for obstructions. I retrieved SD cards every 48 hours and manually reviewed images to track banded rail presence and identified sources of false triggers to guide camera adjustments during my next field visit. These additional steps helped to further refine the camera trapping methodology and ensure that the data collected during the main study was of high quality.

The outcomes of the pilot study were positive, with banded rails being detected from the first day of deployment. The study revealed that camera height and angle needed to be adjusted based on the vegetation present and the need to ensure that banded rails would pass through the focal point. Additionally, the cameras were left at each plot for three nights before being moved to the next, with a total of nine nights being sufficient for detecting rail presence. Finally, SD cards and batteries were checked every three nights when the cameras were moved to the next plot. These findings provided valuable information for the main study and helped to optimize the camera trapping methodology.

In terms of limitations or potential sources of bias, it is important to note that the pilot study was only conducted at one site, which may not be representative of other sites included in the main study. Additionally, the pilot study was conducted during a specific time period, and the results may not be applicable to other times of the year when banded rails may have different activity patterns. To address these limitations, the main study included multiple sites across different habitats and was conducted over a longer period to account for potential seasonal variation in banded rail behaviour.

Figure 3.1: Satellite image of Summerset Village in Hobsonville, in the upper Waitematā Harbour. The study area is outlined (in red) for the camera trapping pilot study. Image source: Google Earth, October 2022.

3.2.3 Main Study Sites

A subset of nine sites were randomly selected from the 20 sites described in Chapter One to evaluate the effectiveness of camera trapping as a monitoring technique (Figure 3.2). The selection of these sites was based on equipment availability and time constraints. To ensure a representative range of banded rail footprint densities, the subset of sites was chosen to include three sites with high footprint density, three with medium footprint density, and three with low footprint density or no footprints recorded, as determined by surveys conducted in Chapter Two. The nine sites were selected randomly within each of the representative footprint ranges (high, medium and low/absent). Table 3.1 provides a summary of the selected sites, including their habitat features and footprint density ratings. Additionally, the table includes a column describing potential sources of bias that could have impacted camera trapping results, such as vegetation cover and camera placement.

Figure 3.2: Satellite image showing the nine survey locations (indicated by red dots) selected for the deployment of camera traps to assess their effectiveness as a monitoring technique for banded rails in the upper Waitematā Harbour. Image obtained from Google Earth, October 2022.

Table 3.1: Study sites selected for testing camera trapping as a monitoring technique for banded rails in the upper Waitematā Harbour, Auckland, New Zealand, with habitat features and footprint density ratings. The table also includes potential sources of bias that may have affected camera trapping results.

Site name	Habitat features	Footprint density rating	Potential sources of bias
Summerset village (pilot study site)	Mature and young mangroves, salt marsh, adjacent freshwater input	High	Dense vegetation cover may have obscured some camera traps
Kauri point domain	Mangroves, salt marsh, extensive wetland, freshwater inputs, public walking track	High	Public walking track may have deterred some banded rails from entering camera trap areas
Wharepapa reserve	Mature mangroves, scattered salt marsh, freshwater input	High	None observed
Oratau Place	Narrow strip of mangrove forest, large coastal trees, scattered salt marsh, freshwater stream	Medium	Camera traps may have been affected by animal behaviour near stream
Whenuapai village hall	Medium and mature mangroves, scattered salt marsh, freshwater stream	Medium	None observed
Riverhead point	Isolated strip of mangroves, no saltmarsh vegetation, no freshwater input	Medium	None observed
Lancaster Road	Mature and young mangroves, large coastal trees, no salt marsh, freshwater input	Low	None observed
The Landing B	Mature mangroves, small wetland, connected to reserve, large tidal river	Low	Dense vegetation cover may have obscured some camera traps; banded rails may have avoided camera traps due to proximity to human activity
Herald Island	Isolated mature and young mangroves, grasses and scattered salt marsh, no freshwater input	None	Camera placement may not have captured the entire banded rail population; banded rails may have avoided camera traps due to isolation from other mangrove forests

3.2.4 Temperature and Weather Conditions

Average monthly temperatures ranged from 14°C to 16°C during the survey period (28 June 2022 to 12 September 2022). Monthly rainfall accumulation ranged from 69 mm to 97 mm. The average wind speed ranged between 23.1 and 25.1 km/h.

3.2.5 Camera Deployment and Placement

Camera deployment and placement played a critical role in the success of the survey. Multiple cameras were strategically deployed at numerous sampling points to increase the likelihood of detecting banded rails and other similarly-sized species and to maximize spatial coverage at each survey location. Furthermore, it enabled the indirect capture of other similarly-sized species, including predator species, that occur in the same habitat. The survey design and camera placement in this study followed the same plot layout as the footprint surveys described in Chapter Two, ensuring continuity and comparison with previous data.

Five Bushnell Trophy Cam Aggressor HD 119774C cameras were deployed in the field during low tide, which provided access to the intertidal zone (Figure 3.3). Each camera remained at a plot for three nights (~72 hours) before being relocated to the next plot (3 plots in total per site). After completing nine nights of deployment, the cameras were retrieved at the next low tide. This approach allowed for data collection over a sufficient period while minimizing any potential disturbance to the study area.

Figure 3.3: Indiana Mallinder-Capamagian installing a camera trap at Kauri Point Domain in the upper Waitematā Harbour, July 2022. Photo: D. Mallinder-Capamagian.

At each survey location, five camera traps were deployed following the same quadrat arrangement used in the footprint surveys (Figure 3.4). Cameras were positioned on the edge of the 10 x 10 m plot facing inwards, with one camera at each of the four corners and one in the plot's centre. The placement of the centre camera varied depending on the vegetation present. Traps were not purposefully directed towards predicted animal passage and remained un-baited throughout the study.

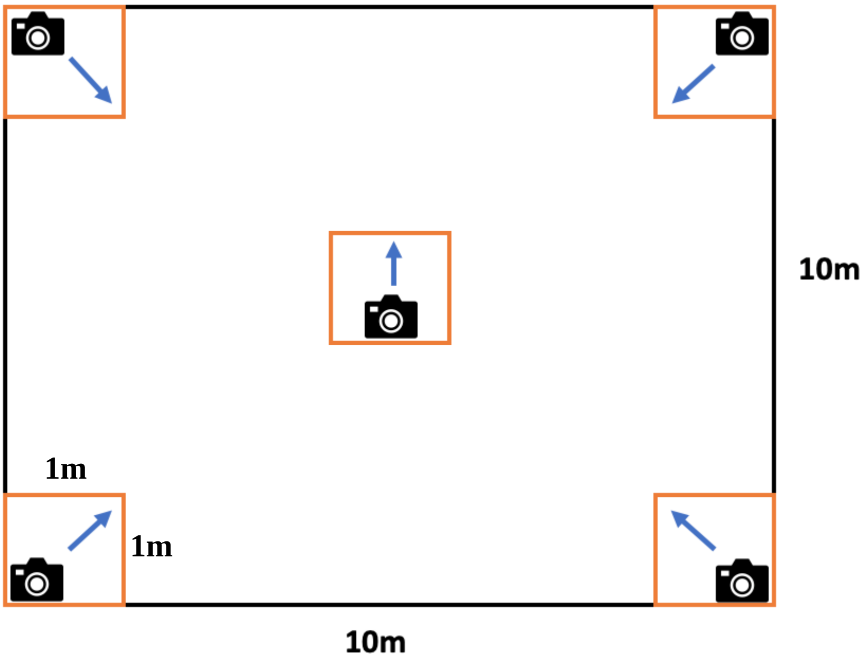

Figure 3.4: Illustration of 5 camera traps deployed within a 10 m x 10 m plot using the same 1m x 1m quadrat layout as the footprint surveys in Chapter Two. The orange squares represent the quadrat positions, and the blue arrows indicate the direction of each camera.

To ensure consistency, the camera traps were mounted on metal posts using a bolt and wooden mounting piece (Figure 3.5). The same camera alignment was maintained for the duration of the camera's time at each plot. By adopting these measures, I was able to capture accurate and comparable data across all survey locations.

Figure 3.5: Photographs showing a camera trap securely mounted on a metal post using a wooden mounting piece and bolt (Left), and the camera traps' positioning in the field (Right) at Summerset Village in the upper Waitematā Harbour, June 2022. Photographs by I. Mallinder-Capamagian.

3.2.6 Camera Height, Orientation and Distance to Detection Zone

Camera height, orientation, and distance to detection were critical factors in optimizing the success of the survey. The suggested camera height for medium to large mammals is between 30-50 cm (Colyn et al., 2017), but since banded rails are medium-sized and reluctant fliers, camera height varied between sites depending on the habitat and location within the intertidal zone. Cameras closer to the coastal edge could be positioned lower than those further out in the estuary or near a deep channel. Camera height ranged between 60-145 cm, with an average height of 102.5 cm. Due to the unique subtidal mangrove habitat in which the cameras were set, the average height of traps was higher than usual, accounting for tidal movements.

Camera orientation was directed slightly downwards and horizontally to the ground to optimize detection success, as suggested by the literature (Caravaggi et al., 2020; O'Brien & Kinnaird, 2008). The cameras were positioned at a distance of ~1.0 m from the optimal detection zone, as determined during the pilot study. The orientation of cameras varied between sites, ranging from 10-40° facing downward, depending on the habitat and vegetation type.

To ensure consistency, camera height and orientation remained unchanged for the duration of the study, except when deemed unsuitable due to a significant amount of false triggers. Unsuitable positioning was identified by image analysis preceding each site visit, and only minor modifications, such as removing small mangrove branches blocking the direct field of view, were implemented where necessary to avoid altering animal behaviour and affecting detection probabilities.

3.2.7 Camera Settings

The pilot study revealed that captures are more likely when the camera is programmed to take both videos and photographs during a trigger event. This was determined when a banded rail was captured passing the detection zone on video; however, it was moving too fast to be captured by the images taken preceding the video. Therefore, all cameras were programmed on the 'hybrid' setting in which video and photographs were taken during one trigger event. The cameras were set to record 10 seconds of video, followed by three consecutive still images using the "rapid-fire" setting. Cameras were programmed on medium sensitivity and set to run continuously for 24 hours a day. The trigger interval was set to 1 second, meaning the camera waited 1 second to respond to any additional triggers from the PIR after an animal was first detected and remained in the sensors' range.

3.2.8 Data Analysis

After each field visit, photographs and videos were manually reviewed, and species were identified. An inventory of other species captured was also documented. Multiple images of banded rail taken in the same minute or successive minutes (within 5 minutes) were treated as a 'single event' unless different individuals could be identified. This protocol of filtering images into 'separate events' was adopted from Meek et al. (2014).

To ensure transparency and replicability of the methods, one camera trap night was defined as 24 hours from 00:00 to 24:00, during which the camera was operational (Meek et al., 2014). Camera trap effort was determined using the total number of camera trap nights from deployment until memory card retrieval, multiplied by the number of individual operational camera traps (Znidersic, 2017). Trap success was calculated as the number of trap events per 100 trap nights.

During the data collection process, I encountered some challenges, such as inclement weather and equipment malfunctions. To address these issues, I monitored weather forecasts and adjusted camera trap deployment times as needed to avoid exposure to extreme weather. I also regularly checked and maintained equipment to ensure proper functioning. Another challenge I encountered was the presence of non-target species in the study area, which could potentially interfere with the detection of banded rails. To minimize this interference, I separated any non-target species that were detected in the camera trap footage and made note of their presence in an inventory. Overall, these measures helped to minimize potential sources of bias and ensure the accuracy of the results.

3.2.9 Statistical Analysis

I conducted a comprehensive statistical analysis of camera trap count data to investigate the relationship between the frequency of banded rail captures and various environmental and biotic factors. The data was split into training and test sets, and all predictor variables were standardized. I fitted Generalized Linear Mixed Models (GLMMs) with Poisson regression and ridge regularization (alpha=0) to the training data using the gmlnet package (Friedman et al., 2010), in R Version 1.4.1717 (R Core Team, 2021). Ridge regression is a commonly used method for analysing datasets with high multicollinearity to determine the explanatory variables' significance, including freshwater presence, predator presence, mangrove size, salt marsh size and plot number. To account for potential variation in camera sensitivity, camera ID was included in the modelling as a random effect, while all other predictors were included as fixed effects.

To determine the optimal value of the tuning parameter lambda, which controls the amount of regularization applied to the model, I employed cross-validation. I used the minimum lambda value associated with the one-standard-error rule to select the final model. I then used the “predict” function in R to predict the number of captures for the test data set, with the lambda value that gave the minimum deviance. To evaluate the model's performance, I used mean squared error (MSE) and root mean squared error (RMSE).

3.3 RESULTS

This study confirmed the presence of banded rails at seven out of nine survey sites, while the absence of banded rails was noted at Herald Island and Lancaster Road (Table 3.2). The Kauri Point Domain and Landing B sites showed the highest number of banded rail events with 85 and 71 events, respectively. Predators were detected at seven survey sites, while no predator presence was observed at the Herald Island and Riverhead sites.

Table 3.2: Detection of banded rails (from highest to lowest) and predator species at survey sites in the upper Waitematā Harbour.

Site name	Banded rails detected	Predators detected	Total number of banded rail events
Kauri point domain	Yes	Yes	**43**
The Landing B	Yes	Yes	**25**
Summerset village	Yes	Yes	**8**
Whenuapai village hall	Yes	Yes	**6**
Wharepapa reserve	Yes	Yes	**4**
Oratau Place	Yes	Yes	**4**
Riverhead point	Yes	No	**1**
Lancaster Road	No	Yes	**0**
Herald Island	No	No	**0**

Over the 74-day survey period, I conducted 81 camera nights across the nine survey locations, resulting in 190 trap events. Of these trap events, 91 were independent avian sightings of the target species (47.89%), 42 sightings of non-target avian species (22.1%), and 57 sightings of predators (30.0%). The total number of trap nights was 405, and the overall trap success rate for all captured animals was 46.9 per 100 trap nights (trap events/trap nights * 100). The mean detection rate for banded rails was calculated as 1.12, based on the number of banded rail events per deployment time.

The cameras captured 23,476 photographs and 3,402 videos, among which 221 were of the target species, accounting for 0.82% of all photos and videos (n = 26,878) (see Appendix B for a breakdown of total images and videos per survey site). The majority of images and videos captured by the cameras were false triggers, caused by various factors such as movement of vegetation due to wind, tidal and water movements, debris movement on the water surface, sun reflection on the water surface, and rainfall. In some instances, animals that moved rapidly past the focal point without being detected could have also triggered cameras, resulting in blank images.

3.3.1 Abiotic and Biotic Factors Influencing Capture Frequency

To compare the effects of different predictor variables, two sets of models were run due to the limited number of predictors and small sample size. The first model included the predictors freshwater, predators, and plot location, while the second model included all five predictors (Table 3.3). The RMSE value of the second model (0.28) was lower than the first model (0.34), indicating that the additional predictors, mangrove and saltmarsh size, are significant in predicting banded rail captures in the upper Waitematā Harbour.

Table 3.3: Coefficients and root mean square error (RMSE) for two models predicting banded rail capture based on multiple predictor variables.

Model	Intercept	Freshwater	Predator	Plot	Mangrove	Saltmarsh	RMSE
1	-1.95	2.61	1.33	-0.11	NA	NA	0.344
2	-1.97	0.28	0.14	-0.12	-6.03e-07	1.003e-07	0.286

Both models identified freshwater presence, predator presence and plot location as significant predictors of banded rail capture. Freshwater was positively related to banded rail captures in both models, with coefficient estimates of 2.61 and 0.28 in Models 1 and 2, respectively. Predator presence was positively related to banded rail capture, with coefficient estimates of 1.33 and 0.14 in Models 1 and 2, respectively. Plot location was negatively related to banded rail capture, with coefficient estimates of -0.11 and -0.12.

In addition to these predictors, the models also revealed some differences in the effects of other environmental factors. In Model 1, mangrove size and salt marsh size were not estimable (marked as "NA", making their effects on banded rail captures inconclusive. However, in model 2, neither of these predictors reached statistical significance (mangrove size: estimate = 6.03e-07, salt marsh size: estimate = -1.003e-07). The presence of freshwater did not appear to be a significant predictor of banded rail captures in either model.

3.3.2 Other Species Observations

In this banded rail study, the cameras also recorded eight bird species, including four native species: New Zealand fantail (*Rhipidura fuliginosa),* silvereye (*Zosterops lateralis*), sacred kingfisher (*Todiramphus sanctus*), and pūkeko (*Porphyrio melanotus*), as well as four introduced and naturalised species: house sparrow (*Passer domesticus),* Eurasian blackbird (*Turdus merula*), song thrush (*Turdus philomelos*), and mallard (*Anus platyrhynchos*). Predatory rats were also captured on camera; however, distinguishing between ship rats (*Rattus rattus*) and Norway rats (*Rattus norvegicus*) was difficult from the images and videos. *R. norvegicus* are typically associated with urban environments and wetlands in New Zealand, while *R. rattus* are generalists and prefer arboreal habitats (Harper et al., 2005; Russell et al., 2019), both of which could be occurring in urban mangrove habitats. Therefore, the rats captured on camera are referred to as *Rattus spp*. in this study.

Table 3.4: Species recorded, conservation status, and capture frequency during the camera trap survey. The conservation status for each recorded species was sourced from (Robertson et al., 2021).

Common name	Scientific name	Number of independant sightings	Capture frequency	National conservation status
Avian				
Banded rail	*Rallus philippensis assimilis*	91	22.4	Native, At risk - declining
New Zealand fantail	*Rhipidura fuliginosa*	1	0.24	Native, Not threatened
Silvereye	*Zosterops lateralis*	2	0.49	Native, Not threatened
Sacred kingfisher	*Todiramphus sanctus*	2	0.49	Native, Not threatened
Pūkeko	*Porphyrio melanotus*	3	0.74	Native, Not threatened
House sparrow	*Passer domesticus*	1	0.24	Introduced and Naturalised, Not threatened
Eurasian blackbird	*Turdus merula*	5	1.23	Introduced and Naturalised, Not threatened
Song thrush	*Turdus philomelos*	1	0.24	Introduced and Naturalised, Not threatened
Mallard	*Anus platyrhynchos*	25	6.17	Introduced and Naturalised, Not threatened

Mammalian				
Ship rat	*Rattus rattus*	57*	14.0	NA – Introduced pest
Norway rat	*Rattus norvegicus*			

* Combined independent sightings of two rat species as the distinction between species is difficult from captured images and video footage.

3.3.3 Behavioural Observations

Cameras captured a variety of rail behaviours, most of which were easily identifiable through the video footage, which was taken preceeding three rapid-fire photographs. Banded rails were captured walking/running through mangrove pneumatophores (Figure 3.6). Rails foraged by probing or pecking the substrate among mangrove vegetation by drilling the bill into the mud substrate. Tail-flicking behaviour was recorded on two occasions and is commonly associated with vigilance and directed towards the direction predators are likely to advance (Alvarez, 1993). Additionally, pairs of rails were observed foraging closely together on two occasions before moving out of the camera's field of view. Other rail behaviours observed included preening (Figure 3.7) and swimming past a camera during high tide (Figure 3.8). No agonistic behaviours towards any of the cameras were recorded during the study.

Figure 3.6: Camera trap image of a banded rail captured walking past a camera trap at Kauri Point Domain, Birkenhead, July 2022.

Figure 3.7: Camoflagued banded rail preening (edited screenshot from a camera trap video), captured at Whenuapai Village, Whenuapai, August 2022.

Figure 3.8: Banded rail swimming past a camera trap (edited camera trap image) at high tide at the Landing, Albany, September 2022.

3.3.4 Temporal Activity Patterns

Temporal activity patterns of banded rail exhibited distinct diurnal peaks, with the majority of events occurring in the morning between 07:00 and 10:00 hr, accounting for 40.6% of the total observations (Figure 3.9). This finding suggests that banded rail may be more active during the morning when foraging opportunities may be more abundant. Additionally, a smaller peak of events was observed between 15:00 and 18:00 hr, which may suggest a secondary foraging period. Notably, no nocturnal activity was recorded, indicating that banded rail may be diurnally active and rely on daylight for foraging and other behaviours.

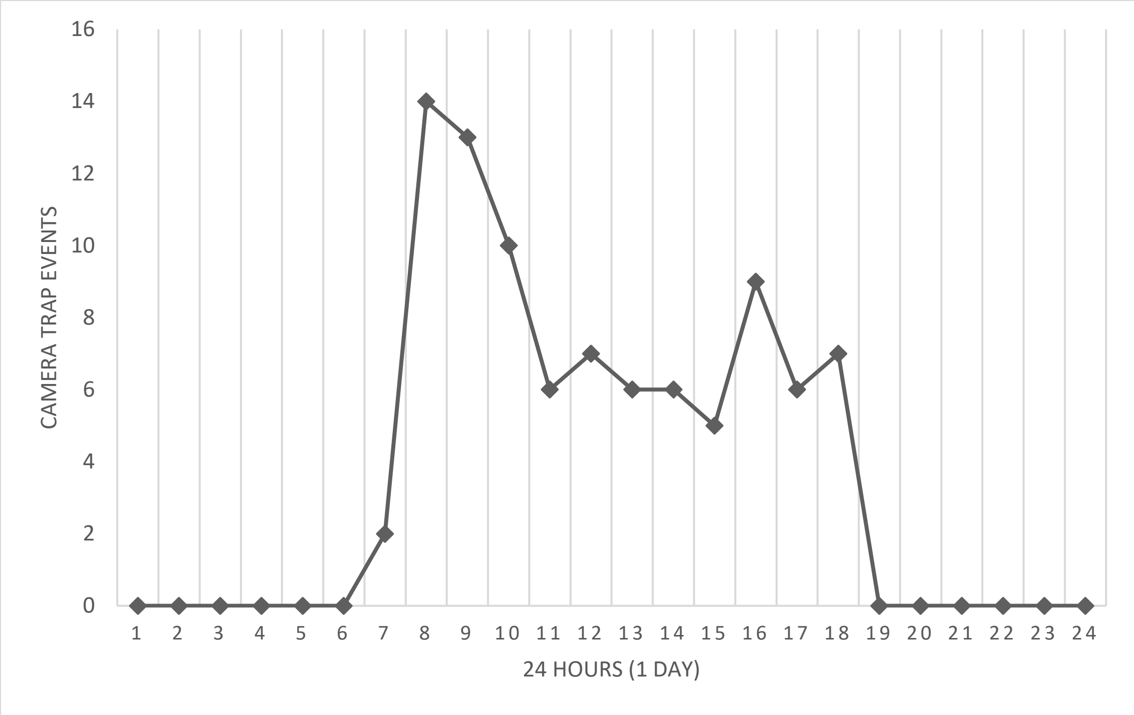

Figure 3.9. Diel activity patterns of banded rail (*n* = 91 events). Events were deemed 'separate' when images captured in the same or successive minutes exceeded 5 minutes. This protocol of filtering images into separate events was adopted from (Meek et al., 2014).

3.3.5 Predator Activity

Rat activity accounted for 30% of observations (*n* = 57 events). No other predator types were observed. Cameras captured a range of rat behaviours, including foraging, climbing the trunks and branches of mangroves, and jumping between mangroves (see Figures 3.10 and 3.11). Rat activity was primarily nocturnal, with peak activity between 21:00 and 22:00 hr (*n* = 9 events) and a second peak between 19:00 and 20:00 hr (*n* = 7 events). Activity also peaked in the early morning hours between 05:00 and 06:00 hr (*n* = 5 events), and rats appeared to be active throughout the night, with the latest recorded event at 05:44.

Figure 3.10: A rat running along the trunk of a mangrove (edited screenshot from a camera trap video) at Wharepapa Reserve, Albany, July 2022.

Figure 3.11: A rat captured passing a camera trap (edited camera trap image) at Lancaster road, Beach Haven, September 2022.

3.3.6 Labour and Equipment Costs

During the study, each monitoring location required approximately 5 hours of fieldwork, resulting in a total of 45 hours (n = 9 survey sites). The fieldwork consisted of deploying and retrieving equipment and relocating cameras twice per site. In addition, regular camera maintenance, such as replacing batteries and SD cards, was performed in the field. The most time-consuming task was manually reviewing the captured images and videos, which took an estimated 48 hours. The cost of each camera was approximately $450, and a total of 15 cameras were used, resulting in an initial investment of around $6,750.

3.4 DISCUSSION

The specific objectives of this study were to assess the reliability and efficacy of camera trapping in capturing banded rail activity and to gather comprehensive inventory data on the presence or absence of banded rails in the study area. My findings demonstrate that camera trapping is an effective tool for detecting the presence and activity patterns of the elusive banded rail in coastal mangrove forests in New Zealand.

3.4.1 Banded Rail Detection and Population Density

Camera traps were found to be effective for detecting banded rails in this study, with the species being detected at 7 out of 9 survey sites. These findings align with previous studies on camera trap use in wetland habitats for closely related species such as the eastern water rail (*Rallus caripes*) (Butt & Hamilton, 2014), underscoring the value of camera trapping for banded rail surveillance in mangroves.

It's essential to acknowledge a key consideration: separate detection events in the study do not necessarily signify distinct individuals. Caution should be exercised when extrapolating these data for density estimates. Factors like individual behaviour, movement pattersn, or repeated sightings may contribute to multiple detections of the same individual. While acknowledging this limitation, the extended camera deployment duration (9 nights per site) and consistent banded rail detections at most sites suggest minimal potential for false absences. However, for a more precise assessment of banded rail population density, complementary methods such as mark-recapture studies are recommended.

3.4.2 Factors Influencing Banded Rail Captures

The statistical analysis revealed that freshwater presence, predator presence, and plot location were significant predictors of banded rail captures. The positive association between freshwater and banded rail captures is consistent with previous studies on the species in New

Zealand (O’Connell et al., 2011), and closely related species overseas (Stoffels et al., 2018). The significant effect of plot location may be attributed to variations in habitat quality and availability in different locations, as has been noted in previous studies on wetland birds (Baldassarre & Bolen, 2006). The finding that predator presence was also a significant predictor of banded rail captures appears contradictory the expected vulnerability of rails to predation (Green & Arnold, 2019). While one might anticipate a negative relationship, my statistical analysis revealed a positive association between predator presence and banded rail capture. This unexpected result prompts further investigation into the nuanced interactions between predators and banded rails in the studied habitat. These findings underscore the complexity of predicting banded rail behaviour and highlight the importance of comprehensive considerations of multiple factors in such ecological studies.

In addition, the lack of banded rail detections at some sites, such as the Herald Island site in this study, which has no freshwater but had salt marsh, and Lancaster Road, which has freshwater but no salt marsh, is intriguing. This suggests that the presence of both freshwater and salt marsh habitats may be necessary for banded rails to occur, as noted in other studies on mangrove birds (Fasola & Canova, 1996; Tordoff et al., 2002). Kauri Point Domain, where the highest number of captures was recorded, is characterized by a large area of salt marsh habitat, recognized as a crucial roosting and breeding habitat for banded rails (Green & Arnold, 2019). These findings support the notion that the availability of suitable habitat plays a crucial role in the occurrence of banded rails in mangrove ecosystems.

The results of this study revealed that mangrove size appeared to have a significant positive effect on banded rail captures in Model 1, but was not a significant predictor in Model 2. This suggests that the relationship between mangrove size and banded rail captures may be more complex than initially thought and may depend on other factors not accounted for in the models. For instance, the positive effect of mangrove size in Model 1 may have been due to the presence of other beneficial features that tend to be associated with larger mangrove patches, such as greater structural complexity or higher prey availability. Additionally, the lack of significant effects for mangrove size in Model 2 could be due to its correlation with other predictors, such as salt marsh size, which were also included in the models. Overall, these results emphasize the need to consider multiple factors when studying the relationship between habitat characteristics and species occurrence, and to interpret the results with caution.

3.4.3 Additional Insights

The use of camera traps provided valuable insights into the behaviour of the elusive banded rail, which would have been impossible to observe through conventional field methods alone. The study revealed important information about the diel and temporal activity patterns of the banded rail in its unique habitat in New Zealand.

Specifically, the results suggest that the typical crepuscular activity pattern observed in banded rails residing in wetlands without adjacent mangrove foraging habitat is not reflected in the populations in this study due to tide restrictions. This information adds to the limited knowledge of banded rail behaviour in New Zealand, which is still largely unknown compared to other rail subspecies overseas.

Furthermore, camera trap data can be used to reveal the temporal activity patterns of banded rail occurring in mangrove forest, which could inform conservation management strategies. For example, identifying the times of day when the birds are most active and move between different habitat types could inform the timing of habitat restoration activities or predator control efforts. These findings are consistent with other studies that have used camera traps to study the behaviour of other secretive bird species in their natural habitats (Caravaggi et al., 2020; Szekeres et al., 2021).

In addition, the higher capture frequency of predators in certain sites raises questions about the potential correlation between predator presence and lower banded rail density. This study revealed that all sites where predators were detected also had banded rails present, but it is worth further investigation whether higher predator capture frequency may have an impact on banded rail populations. These findings are consistent with other studies that have used camera traps to study predator-prey interactions in bird populations (Meek et al., 2015; Struebig et al., 2018).

3.4.4 Limitations

The camera trap study has several limitations that must be considered when interpreting the results. One potential source of bias is that the study was willing to trade off an increase in false triggers for increased detection probability. While this approach may have resulted in higher predator detection rates, it may also have led to overestimation of banded rail density, especially in areas where the camera was optimally located for an increased chance of captures, such as in a preferred foraging area or passage. Additionally, the estimates of site occupation may be biased as the assumption that all animals are detected when they are present is rarely true. We would expect that a lower number of cameras would capture banded rails at low density of birds, and that more cameras would pick up banded rails in the case of high density.

Estimating banded rail density using camera trap data can be challenging, as one camera capturing multiple banded rail events may not reflect true banded rail density. Moreover, to confirm the absence of an animal from a site, an effort of around 1000 trap nights is needed (Kelly & Holub, 2008). Due to time restrictions, this study included only 81 total trapping nights; future studies should look to increase camera effort before making conclusions about a species' absence from a location.

It is important to note that the timing of the camera trap deployment could affect the results. For example, proximity to the breeding season could affect banded rail behaviour, resulting in differences in movement and activity. Additionally, the study deployed cameras across a period of 74 calendar days due to COVID-19 lockdowns and equipment restrictions, which could have introduced differences in timing that may have affected the behaviour and activity of the birds.

In addition to the factors mentioned earlier, camera trap studies can also be affected by potential site-specific sources of bias. For example, dense vegetation cover may obscure some camera traps, making it difficult to capture all individuals within a population. Similarly, camera placement may not capture the entire population of a species, particularly in cases where the species is widely distributed or exhibits low population density. Moreover, public walking tracks or other human activities may deter some individuals from entering camera trap areas, resulting in an underestimation of the population size.

Furthermore, camera traps can be susceptible to errors when the housing is exposed to extreme direct sunlight (Meek et al., 2014). Temperature ranges are likely to influence the detection probability, which can impact the accuracy of population estimates. Additionally, image overexposure caused the loss of some images, which may have affected the accuracy of the data collected.

3.4.5 Conclusions and Recommendations

This study demonstrates the effectiveness of camera trapping as a non-invasive method for monitoring the behaviour and habitat use of rare and elusive banded rails in mangrove habitats. By using this method, we were able to gain valuable insights into the species' behaviour and temporal activity patterns. My findings highlight the importance of considering tidal movement and high tide levels when positioning cameras to avoid potential damage or loss of equipment and minimize false negatives.

Camera traps should be positioned in areas adjacent to salt marsh vegetation to increase detection probability. In survey sites with no salt marsh habitat, camera traps should be placed near freshwater channels in mangrove habitats or adjacent to tall grasses on the coastal edge. Additionally, cameras should be oriented in a way that minimizes false triggers and overexposed images.

This study also demonstrates the advantages of camera trapping over traditional survey methods. It reduces disturbance to the species being monitored, surveys larger areas for longer periods of time, and produces a visual record of the species' behaviour. However, it is important to consider the associated labour and material costs.

Moving forward, I recommend further research to better understand the ecology, movement patterns, and response of banded rails to anthropogenic disturbance. By using camera trapping in combination with other monitoring techniques, we can continue to improve our understanding of this elusive species and work towards its conservation.

3.4.6 Conservation Outcomes

The findings of this study have significant implications for the conservation of banded rails and their habitat. Understanding the habitat use, breeding status, and behaviour of banded rails is critical for developing effective conservation strategies. The use of camera traps in this study has provided previously unattainable information that can be used to inform conservation efforts for this elusive species.

Specifically, the study identified the importance of salt marsh and freshwater channels as essential habitats for banded rails. This information can be used to target conservation efforts and prioritize the protection and restoration of these habitats. In addition, the study identified the potential negative impacts of human disturbance on banded rails, emphasizing the need for management practices that minimize disturbance.

Overall, the results of this study provide valuable insights for the conservation of banded rails in New Zealand, as the approach used in this research can be adapted for use in all habitat types preferred by the banded rail. By using camera traps as a monitoring tool, researchers can continue to gather critical data on the behaviour and ecology of this species, informing future conservation efforts.

CHAPTER 4

An Investigation of the Use of Call-Playback as a Monitoring Technique for the Banded Rail

4.1 INTRODUCTION

Elusive marsh birds that occupy dense vegetation can be difficult to detect using passive survey methods, and many marsh bird monitoring efforts rely on aural surveys for detection (Allen et al., 2004; Conway & Gibbs, 2005). One promising technique for detecting cryptic marsh birds is call-playback (also known as call broadcasting), where researchers broadcast recorded calls to elicit vocal responses from birds.

Call-playback has proven successful for monitoring many international rail species, including the yuma clapper rail (Hinojosa-Huerta et al., 2002), water rail (Brambilla & Jenkins, 2009), black rail (Tolliver et al., 2019), and spotless crake (Kaufmann, 1988). However, limited studies have explored the use of call-playback as a monitoring technique for banded rails (*Hypotaenidia philippensis assimilis*) in New Zealand, and it is unknown whether this technique is viable for long-term monitoring.

Early studies found call-playback to be unreliable in detecting banded rails effectively (Elliot & Graham, 1989). However, more recent studies have shown that call-playback can be effective for detecting banded rails (Crawford et al., 2020). Timing is often crucial for detecting cryptic species, and literature suggests that banded rails are more likely to respond to playback during the breeding season (Graham, 1989). Ideally, call-playback surveys for banded rails should be conducted in either the morning or evening when the birds are most vocal (Conway, 2011). Vocalization probability is generally highest during the two hours surrounding sunrise and sunset (Conway, 2011).

In New Zealand, banded rails occupy habitat associated with dense subtidal vegetation, silt, and boggy substrate that is difficult to traverse, leading to many monitoring constraints. Traditional monitoring methods, such as walking line transects and observing individuals, are challenging to conduct in this habitat type. Therefore, exploring alternative monitoring techniques, such as call-playback surveys, is critical for effective and efficient conservation management of banded rails in New Zealand.

4.1.1 Study Objectives and Conservation Significance

In this chapter, I explored the use of call-playback as a monitoring technique for banded rails in tidal mangrove and marsh habitats within the upper Waitematā Harbour. The specific objectives were to test the reliability of call-playback as a monitoring technique for banded rails and to gather inventory information on the presence and absence of banded rails in the upper Waitemata Harbour. Lastly, I aim to compare the data gathered through call-playback surveys with that obtained from other survey methods such as footprint surveys and camera trapping (Chapter 5). The results of this study will inform conservation managers about the effectiveness of this monitoring technique for banded rails and potentially identify an efficient method for long-term monitoring. Effective monitoring is essential for developing and implementing conservation management strategies for at-risk species such as the banded rail.

4.2 METHODS

4.2.1 Animal Ethics and Considerations

Animal ethics is a crucial consideration in all research involving animals. The Massey University Animal Ethics Committee granted approval for the research conducted in this chapter (Appendix C). The committee ensured that the research was conducted per the New Zealand Animal Welfare Act of 1999, which sets out the legal and ethical standards for using animals in research. In addition, part of the ethical considerations involved consulting with a member of the local Iwi to ensure that the research was carried out in a culturally appropriate and respectful manner. The Te Kawerau Iwi Tiaki Trust provided support and endorsement for this research, ensuring that the project was consistent with the values and beliefs of the local community.

This research did not require a permit from the Department of Conservation as birds were not being handled. However, the research team still took measures to minimize any potential harm or distress to the birds and ensure they were not unduly disturbed during the research process. These measures included using passive survey methods in addition to call-playback and carefully selecting the times and locations for data collection. The welfare of the birds and their natural habitats were paramount in all aspects of this research.

4.2.2 Pilot Study

The pilot study was conducted on 7 October 2022 at the Kauri Point Domain site which was also included in the main study (Figure 4.1). This site was selected for the pilot study due to the confirmed presence of banded rails in both the footprint surveys conducted in Chapter Two and camera trapping in Chapter Three. The primary objective of the pilot study was to test and refine the methodology for call-playback surveys that were to be conducted in the main study.

The results of the pilot study provided strong validation for the planned methodology of the main study, which proved to be both appropriate and effective in detecting banded rails through the use of broadcasted calls. The pilot study confirmed the presence of banded rails at the site and demonstrated that the planned methodology was able to detect their response to the call-playback. Additionally, the study revealed the importance of conducting multiple experiments at different locations within a site, as no birds responded to the first two experiments but responded during the third (see Figure 4.2 for the location of each experiment repetition at Kauri Point Domain during the pilot study). These findings underscored the significance of multiple experiments and their location when conducting surveys. Overall, the pilot study provided confidence in the use of call-playback surveys as a viable monitoring technique for banded rails in the upper Waitematā Harbour.

Figure 4.1: Indiana Mallinder-Capamagian and Weihong Ji (research supervisor) conducting call-playback surveys during the pilot study at Kauri Point Domain in October 2022. Photo by I. Veldhuis.

Figure 4.2: Satellite image of Kauri Point Domain showing the locations of the three call-playback experiments conducted during the pilot study survey. Image obtained from Google Earth, October 2022.

4.2.3 Main Study Sites

Due to logistical constraints and access restrictions, three sites out of the 20 sites initially identified in chapter one were excluded from the call-playback study. These sites, namely Kereru Grove, Sanders Reserve, and Kaipatiki Road, were deemed unsafe to access in the dark. Therefore, the study was conducted at 17 sites (refer to Table 4.1) located in tidal mangrove and marsh habitats in the upper Waitemata Harbour. The selected sites were chosen based on the presence of suitable banded rail habitat, accessibility, and confirmed or suspected banded rail presence from previous surveys, such as footprint surveys and camera trapping.

Table 4.1: Location and GPS coordinates of study sites for banded rail call-playback surveys.

Location	Site name	S	E
Albany	Albany Cemetery	36.7554881	174.6778444
	Wharepapa Reserve	36.7493399	174.6784279
	The Landing A	36.7270879	174.6933671
	The Landing B	36.7287897	174.6898659
Greenhithe	Oratau Place	36.7705679	174.6658973
Beach Haven	Kahika Point Reserve	36.7847629	174.6981525
	Lancaster Road	36.7844374	174.6919224
	Tui Park	36.7867034	174.6844562
	Kauri Point Domain (Pilot study site)	36.8131984	174.6980302
Herald Island	Herald Island	36.7755161	174.6609359
	Kingsway Road	36.7821461	174.6460195
Hobsonville	Summerset Village	36.7887943	174.6524987
	Limeburners Bay	36.8028938	174.6508156
Whenuapai	Pohutakawa Road	36.7763953	174.6440081
	Whenuapai Village Hall	36.7772931	174.6357416
	Dale Road	36.7782209	174.6180963
Riverhead	Riverhead Point Drive	36.7627379	174.6005969

4.2.4 Data Collection

Count data were collected on the frequency of banded rail calls in response to broadcasted calls during playback experiments at the 17 sites. To conduct the call-playback surveys, I used a UE Boom Bluetooth speaker to broadcast banded rail calls obtained from a past

Massey University student. The recorded calls included various call types from a population of banded rails in the Mangawhai Harbour that were recorded using a handheld recording unit (Marantz solid-state recording unit with Sennheiser MKE 600 microphone and Rycote Softie). The precise functions of these calls, whether they pertain to territory marking, courtship rituals, or other influences on observed responses, remain unidentified. Further research is necessary to investigate banded rail call function.

Three different types of banded rail calls were broadcasted during each call-playback experiment, with each call type played separately in the same order (see Appendix D for spectrograms of each call). To ensure clarity and minimise background noise, an audio technician edited the audio files of the calls before the experiments. This involved the application of a limiter to enhance the perceived loudness of the banded rail calls. The limiter employed a brick wall compression technique, preventing noise from exceeding the clipping point of 0dB. This process effectively heightened the perceived loudness of the quieter parts of the sound, highlighting the banded rail call notes as much as possible for broadcasting.

The broadcast sequence consisted of 30 seconds of banded rail calls, followed by 30 seconds of silence (Conway, 2011), and this sequence was repeated for each call type. This approach aimed to simulate natural calling patterns and increase the likelihood of detection. Each experiment began with a 3-minute silence period to habituate to the location, followed by 3 minutes of passive listening to spontaneous vocalisations, a 3-minute broadcasting segment, and another 3 minutes of passive listening post-playback. Calls were played at maximum volume to enhance detectability.

To ensure a permanent record of the surveys and overcome the challenge of detecting low-volume calls, a handheld recording unit (Marantz solid-state recording unit with Sennheiser MKE 600 microphone and Rycote Softie) was used to record at a sampling rate of 48 kHz. the recording equipment was set up before arriving at each survey location to minimize noise disturbance.

To increase the probability of detecting banded rails at a site, three call-playback experiments were conducted at different locations during each survey. The entire survey was repeated twice at each site, with a minimum of 36 hours between repetitions, to minimize vocal habituation and ensure fresh conditions for each experiment.

Experiment locations varied as the habitat permitted and were sometimes biased depending on site characteristics and previous knowledge of banded rail habitat use and ecology. For example, locations were stationed on the periphery of mangrove forests and/or areas of salt marsh habitat if present. Experiment locations were at least 100 m apart, depending on site characteristics. GPS coordinates were marked on google maps for each experiment location.

During some surveys, an additional two surveyors accompanied me and assisted in using a stopwatch to time the experiments.

4.2.5 Timing and Environmental Conditions

The surveys were conducted during the breeding season of banded rails, as they are more vocal and active during this time, thus increasing the likelihood of detection (Dowding & Murphy, 2001). In New Zealand, banded rails' breeding season usually occurs from September to February, with peak breeding activity from October to December (Taylor et al., 2015). Surveys began one hour before sunrise to further optimize the chances of detecting banded rail calls. Banded rails are crepuscular, and studies have shown that they are most active an hour before dawn and an hour after sunset (Clausen et al., 2012).

The surveys were conducted only under favourable environmental conditions. Specifically, surveys were carried out on calm mornings with no precipitation and wind speed below 20 km/hour. Rain and wind can interfere with the aural detection of calls and reduce the chances of detecting banded rails (van de Pol et al., 2010; Braun and Petty, 2012). Due to time constraints, the surveys were conducted at various tidal states and were not standardized. However, the tidal state at the time of each survey was recorded.

4.2.6 Data analysis

To identify vocalizations of banded rails in the audio recordings, I used the interactive sound analysis software Raven Lite, Version 2.0.5 (Cornell Lab of Ornithology, 2021). A vocalization was defined as the complete series of calling notes from start to end. For each vocal response, I manually recorded the start, end, and duration of calling. The frequency of response calls and calls heard during passive listening periods were recorded in a spreadsheet for further analysis. A vocalization was categorized as a "response" to a recorded call if detected within 30 seconds after the call was broadcasted. Additionally, a bird’s call during the playback was considered a “response”. Conversely, if a call was detected outside this 30-second window, it was classified as "passive" and not attributed to a response to the broadcasted call.

4.2.7 Statistical Analysis

To examine the relationship between the frequency of banded rail responses to call-playback and various environmental and biotic factors, I conducted a statistical analysis on the call count data collected from 34 surveys. Genrealied Linear Mixed-Models (GLMMs) with Poisson distribution and a bionomial distribution and logit link function were fitted using the ‘lme4’ package (Bates et al., 2015), in R Version 1.4.1717 (R Core Team, 2021), with the significance level set at P <0.05. Prior to modelling, the predictors were standardized. To address potential variation in response call frequency across sites, site was included as a random effect in the mixed-effects model.

The analysis focused on response calls, considering instances where banded rails vocalized within 30 seconds after the call-playback, as well as passive calls detected during the designated passive listening periods. Both types of calls were included in the overall count data used for statistical modelling.

A model selection approach was used to determine which explanatory variables were most important for predicting the response variable by comparing Akaike’s Information Criterion (AIC) and P values. Factors tested for their potential effect on call frequency included the size of mangrove and saltmarsh habitats, tidal state during surveying, presence of freshwater, and presence of predators. Since predator presence can’t be determined using call-playback surveys, the data used in this analysis for predator presence was obtained from the footprint and camera trap surveys carried out in Chapters Two and Three previously.

It is essential to highlight that the dataset contains numerous zeros, indicating infrequent bird detections using this monitoring technique. To address this, zero-inflated Poisson (ZIP) models were also considered in the analysis.

4.3 RESULTS

Between 7 October and 4 December 2022, 34 call-playback surveys were conducted. Banded rails were detected aurally at 5 out of 17 total sites (29%), confirming banded rail presence (Figure 4.3). Broadcasted calls elicited a total of 56 individual responses from banded rails. The highest number of response calls was recorded at The Landing B site, with 18 calls representing 32.14% of the total calls recorded (Table 4.2). The second highest number of response calls was at Kauri Point Domain, with 17 calls representing 30.36% of the total. Albany Cemetery had the third-highest number of response calls, with 13 calls representing 23.21% of the total. Additionally, one passive call was recorded while walking between the second and third experiment locations at the Kauri Point Domain site. This call was spontaneous and not in response to a broadcasted call.

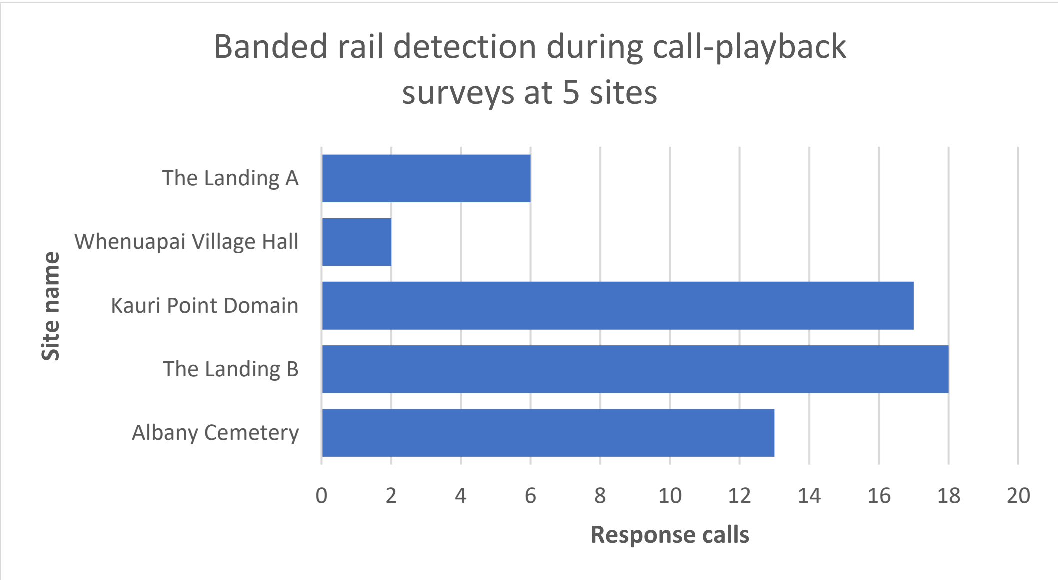

Figure 4.3: Bar chart showing the number of banded rails detected during call-playback surveys at five sites. The X-axis represents the number of response calls recorded, and the Y-axis represents the site name

Table 4.2: Summary of call-playback survey results: freshwater, predator and salt marsh presence, response counts, and percentages by site from highest to lowest.

Site name	Freshwater	Salt marsh	Predators	Response calls	Percentage
The Landing B	Yes	Yes	Yes	**18**	32.14%
Kauri Point Domain	Yes	Yes	Yes	**17**	30.36%
Albany Cemetery	Yes	Yes	No	**13**	23.21%
The Landing A	Yes	Yes	No	**6**	10.71%
Whenuapai Village Hall	Yes	Yes	Yes	**2**	3.57%
Pohutakawa Road	Yes	Yes	No	**0**	0%
Wharepapa Reserve	Yes	Yes	Yes	**0**	0%
Oratau Place	Yes	Yes	Yes	**0**	0%
Kahika Point Reserve	No	No	Yes	**0**	0%
Lancaster Road	Yes	No	Yes	**0**	0%
Herald Island	No	Yes	No	**0**	0%
Kingsway Road	No	Yes	Yes	**0**	0%
Summerset Village	Yes	Yes	Yes	**0**	0%
Limeburners Bay	No	No	No	**0**	0%
Tui Park	No	No	No	**0**	0%
Dale Road	No	No	No	**0**	0%
Riverhead Point Drive	No	No	No	**0**	0%

Banded rails responded during all three experiment repetitions at the five sites that recorded response calls (Table 4.3). Banded rails were responsive to all three call types that were broadcasted throughout the experiements. Playback number 3 was the most effective call type, eliciting 80% of the total responses, whereas playback number 1 only elicited 5% of the total responses (n = 3 calls) (Table 4.4).

Table 4.3: Number and percentage of response calls heard during each experiment repetition at 17 sites in the call-playback surveys.

Experiment	Response calls	Percentage of total resonse calls
1	19	26.76%
2	15	21.13%
3	22	30.00%
Total	56	78.87%

Table 4.4: Total response calls for each banded rail call type and site.

Site name and survey number	Call type 1	Call type 2	Call type 3	Total
Landing A (Survey 1)	0	0	5	5
Landing A (Survey 2)	1	0	0	1
Landing B (Survey 1)	2	1	8	11
Landing B (Survey 2)	0	5	2	7
Albany Cemetery (Survey 1)	0	0	13	13
Kauri Point Domain (Survey 1)	0	0	13	13
Kauri Point Domain (Survey 2)	0	0	4	4
Whenuapai Village (Survey 1)	0	2	0	2
Total	**3**	**8**	**45**	**56**

During three surveys, some responding banded rails approached the playback speaker as their calls grew louder, suggesting they were getting closer to the surveyor. Specifically, this behaviour was observed at Landing A, Landing B, and Kauri Point Domain, all of which contain large areas of salt marsh habitat in close proximity to the survey location. In two separate surveys at Albany Cemetery and Kauri Point Domain, I observed two banded rails responding to each other's calls following a broadcasted call. While most of the response calls were indicative of a single individual based on the direction and volume of the call, it is impossible to ascertain with certainty. Notably, some of the response calls were similar but distinct from the calls that were broadcasted, suggesting the possibility of different dialects or natural individual variation.

Despite hearing vocalizations from responding banded rails at an estimated distance of fewer than 10 meters, no visual observations of the birds were recorded during the experiments.

4.3.1 Abiotic and Biotic Factors Influencing Banded Rail Detection

The analysis of banded rail response calls revealed that the zero-inflated Poisson (ZIP) model provided a better fit for the data compared to the standard Poisson model (Table 4.5). The ZIP model had a lower AIC value (118.84) compared to the Poisson model (125.13), indicating a better fit of the ZIP model to the data. The count model coefficients in the ZIP model were similar to the ones obtained from the Poisson model (Tables 4.6 and 4.7), with a significant positive effect of tide level (estimate = 0.37, P = 0.031) on the number of response calls made by the banded rails. However, the zero-inflation model intercept in the

ZIP model (estimate = 1.25, $P = 0.0000775$) indicated that there were excess zeros in the data, which were not accounted for by the Poisson model. These excess zeros were likely due to the banded rails not calling in certain conditions or locations.

Table 4.5: Comparison of Poisson and ZIP models for banded rail response calls, showing Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Log-likelihood, Deviance and number of parameters

Model	AIC	BIC	Log-likelihood	Deviance	No. of parameters
Poisson	125.13	133.5	-59.56	119.13	5
ZIP	118.84	127.2	-53.42	106.84	5

Table 4.6: Poisson model coefficients and significance levels

Coefficient	Estimate	Standard error	Z value	P value
Intercept	-0.52	0.25	-2.08	0.038
Tide level	0.40	0.19	2.11	0.035*
Mangrove size	0.28	0.17	1.64	0.100
Freshwater availability	0.04	0.21	0.19	0.849
Predator presence	0.16	0.23	0.71	0.476

Table 4.7: Zero-inflated Poisson (ZIP) model analysis of banded rail response calls: key predictor variables and their coefficients

Variable	Coefficient	Standard error	Z value	P value
Intercept	1.25	0.236	5.29	0.0000775
Tide state	0.37	0.176	2.10	0.031*
Mangrove size	0.22	0.184	1.20	0.231
Freshwater availability	-0.15	0.193	-0.78	0.438
Predator presence	-0.03	0.227	-0.14	0.889

The results indicated that tide state is significantly associated with the count of response calls made by banded rails ($P = 0.03$), with freshwater availability and predator presence not found to be significant predictors. These findings suggest that the tidal state at the time of surveying plays important roles in determining the behaviour of banded rails and their response calls.

The use of a ZIP model highlights the importance of accounting for excess zeros in count data, improving the accuracy and reliability of statistical analyses.

The scatter plot (Figure 4.4) shows the relationship between tide state, mangrove forest size, and the count of response calls made by banded rails. I observed a positive relationship between tide state and the count of response calls, with higher response call counts occurring at higher tide levels. In addition, there appears to be a positive relationship between mangrove forest size and response call count, although this relationship is less clear than the relationship with tide state and it appears that after a certain point, larger mangrove forests had less call responses. The scatter plot suggests that tidal state and mangrove forest size may both play important roles in determining the behaviour of banded rails and their response calls.

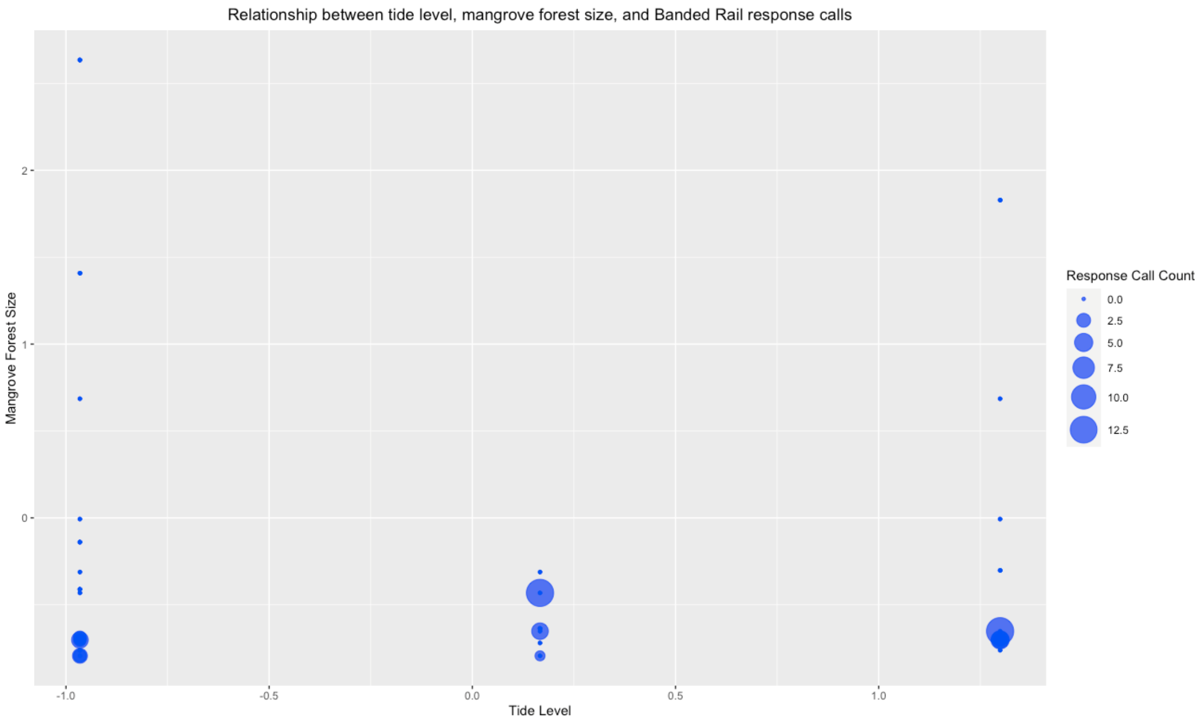

Figure 4.4: Scatterplot showing the relationship between tide level, mangrove forest size, and banded rail response calls. The size of the dots represent the count of response calls, with larger dots indicating a higher count. The tide level on the left-hand side of the plot represents low tide, with high tide on the right-hand side and mid-tide in the centre.

4.3.2 Labour and Equipment Costs

During the course of this study, approximately 29 hours were dedicated to conducting surveys and travelling to and from the survey locations. The survey locations were conveniently situated on the coastline, which enabled easy and quick access without the need to enter the mangrove habitat. In addition, around 20 hours were spent on reviewing audio files, which were recorded using specialized Marantz solid-state recording units and a Sennheiser MKE 600 microphone, along with additional microphone accessories such as the Rycote softie with mount and grip. The recording equipment used in this study incurred an initial investment total cost of approximately $1250.

4.4 DISCUSSION

This study aimed to investigate the effectiveness of call-playback surveys in detecting the elusive banded rail and whether call-playback surveys can be a viable monitoring option. The results suggest that call-playback surveys can be effective in detecting banded rails, as 98.21% of banded rail calls were detected shortly after broadcasting a recorded call. However, it's important to acknowledge that the banded rail detection rate in this study was low and that the data presented a high frequency of zero detections, which highlights the elusive nature of this species and the potential limitations of call-playback surveys for detecting banded rails.

4.4.1 Banded Rail Detection

The low detection rate of banded rails in this study, with only 5 out of 17 sites confirming their presence through call-playback surveys, suggests that banded rails may be more difficult to detect than previously thought. These findings are consistent with other studies that have used call-playback surveys to gather inventory information on banded rails and similar rail species. For example, Smith and colleagues (2018) found that call-playback surveys had a low detection rate for the Spotless crake, a species closely related to the banded rail. However, it's important to consider the possibility of false absences in this study, as the low detection rate could be due to the banded rails' reluctance to call in response to playback surveys. Previous studies have shown that rail species may be less likely to call in response to playback surveys compared to other bird species (Brosset et al., 2015). Therefore, it's possible that banded rail were present at sites where they were not detected, leading to false absences in the data.

It is worth noting that certain response calls were observed to be different from the calls that were broadcasted, although they shared some similarities. The broadcasted calls in question were of banded rails located in Mangawhai Harbour, which is a different geographic location. It is not surprising that the response calls would be different since the banded rails in the two locations may have developed distinct dialects. This discovery highlights the need for future studies to explore dialectal differences among banded rails, as it may have an impact on response rates. To the best of my knowledge, no studies have yet investigated dialectal differences among banded rails, and it is worth noting that such differences may affect response rates in future studies.

4.4.2 Factors Influencing Call Response

The results of the study suggest that tide state and mangrove forest size are important factors that influence banded rail behaviour and vocalization patterns. Specifically, the modelling showed that surveys conducted at high tide were more likely to elicit a response from banded rails. These findings are consistent with previous research on the ecology of banded rails and wetland birds more broadly (Gill et al., 2018; Rowley et al., 2019). For instance, a study on the ecology of the black rail found that tidal flooding and water levels were important in shaping the species' vocalization patterns (Watts et al., 2016). The literature suggests that higher tide may be an important factor in detecting banded rails during call-playback surveys. Higher tide may force the birds to move to higher ground, making them more visible and easier to detect, and reduce their foraging area, concentrating them in smaller areas. Additionally, banded rails may vocalize more frequently during high tide periods, increasing their detectability. Studies have found higher detection rates of banded rails during high tide periods. Further research is needed to fully understand the mechanisms behind this phenomenon. (O'Donnell et al., 2011; Henderson et al., 2015). Another study on the related buff-banded rail also found that mangrove cover and the presence of predators influenced the species' calling behaviour (Baldwin et al., 2017).

It is important to consider other potential factors that could have influenced banded rail responses but were not investigated in this study. For instance, weather conditions such as wind speed and temperature have been shown to impact the calling behaviour of wetland birds (Amirpour et al., 2017). Additionally, while time of day was standardized for all surveys in this study, it is possible that variation in the timing of surveys across different sites could have influenced response rates.

The use of a zero-inflated Poisson (ZIP) model allowed for a more accurate analysis of the data by accounting for the excess zeros in the count of response calls. This approach can be valuable in future studies of wetland bird vocalizations and may help to improve the reliability and validity of statistical analyses in this field. These findings align with other studies that have identified similar factors influencing call response in wetland birds (Schaub et al., 2015).

4.4.3 Limitations

This study has several limitations that should be acknowledged when interpreting the results. Firstly, the lack of visual observations of the birds during the study is a significant limitation. Call-playback surveys can detect birds' presence, but they do not provide information on individual behaviour or other ecological variables that might be important for understanding species distribution and abundance. While this technique is widely used for monitoring bird populations, it should be recognized that it has its limitations and can result in false negatives and underestimates of population size (Kery et al., 2010).

The high number of zeros in the data is another limitation of this study. Although the use of a zero-inflated Poisson model accounted for this excess of zeros, it is possible that banded rails were present in areas where they were not detected during the surveys. This issue is particularly relevant when estimating population size, as it requires accurate estimates of density and distance to individuals, which can be challenging with call-playback surveys (Sólymos et al., 2018).

The breeding season is also an essential factor that should be considered when interpreting the results of call-playback surveys. In New Zealand, the banded rail breeding season typically starts in August and extends until March, with many pairs laying their eggs by October (Wilson et al., 2005). The exact timing of egg-laying can vary depending on various factors such as habitat conditions, local climate, and food availability, among others. These factors could impact the vocalization behaviour of banded rails and influence their response rates to call-playback surveys.

Call-playback surveys are also restricted by the time of day and are best conducted at sunrise or sunset due to the crepuscular nature of the birds (Rowley et al., 2019). Tidal movements can also restrict surveyor positioning, as they cannot enter mangrove habitat during surveys at high tide, potentially missing vocalizations from rails that are present in other areas of mangrove habitat that is inaccessible (Watts et al., 2016). Habitat size is another limitation, as birds may be present on the other side of a large habitat area, making it difficult to hear broadcasted calls (Baldwin et al., 2017).

Finally, noise interference is another significant limitation when conducting call-playback surveys in a semi-urban environment. In this study, noise from various sources, including traffic, roadworks, helicopters, boats, road and housing construction works, and wind may have influenced the detection of banded rail vocalizations. These noise sources could have resulted in false negatives, limiting the study's ability to accurately detect and estimate banded rail populations in urban environments. Additionally, The technique's efficacy also depends on the trained surveyor's ability to hear and identify the individual (Neice & Mcrae, 2021).

4.4.4 Conclusions and Recommendations

In conclusion, this study aimed to test the reliability of call-playback as a monitoring technique for banded rails in tidal mangrove and marsh habitats within the upper Waitemata Harbour, and to gather inventory information on the presence and absence of banded rails in the area. While the results suggest that call-playback surveys may not be a reliable method for monitoring banded rails, as rails were only detected at five of the surveyed sites, this study still provides valuable information for conservation managers. The study highlights the limitations of call-playback as a standalone monitoring technique and emphasizes the need to use a combination of monitoring techniques to obtain a more comprehensive understanding of banded rail ecology, behaviour, and distribution.

This study has also identified several factors that can influence the effectiveness of call-playback surveys, such as tidal movements, habitat size, survey timing and noise interference. These factors should be considered when designing monitoring programs for banded rails or other wetland bird species. The possibility of dialectal differences among banded rails, suggested by the differences between the broadcasted calls and response calls, is an interesting area for future research that could have implications for the effectiveness of call-playback surveys in different geographic locations and could shed light on the genetic and ecological factors shaping vocalization patterns in this species.

Future studies should also consider testing call-playback surveys as a monitoring technique for banded rails outside of their breeding season. It is worth noting that this study was conducted during the breeding season, which is when banded rails are most active and vocal. Therefore, testing call-playback surveys outside of the breeding season could help evaluate the techniques' effectiveness when banded rails are less vocal and more difficult to detect. This would be particularly important for conservation efforts, as detecting banded rails outside of the breeding season is crucial for understanding their distribution and habitat use throughout the year.

Overall, this study provides valuable insights into the factors that influence the vocalizations of banded rails and can inform conservation efforts to protect this species. Effective monitoring is essential for developing and implementing conservation management strategies for at-risk species such as banded rails, and this study highlights the need for a multifaceted approach to monitoring and managing these species in wetland environments.

4.4.5 Conservation Outcomes

The conservation outcomes of this study are significant, as the use of call-playback surveys provides a potentially cost-effective and less labour-intensive method for monitoring banded rail populations in tidal mangrove and marsh habitats. By demonstrating the effectiveness of this method, this study can inform conservation managers and help them allocate limited resources more effectively towards monitoring and managing at-risk species like the banded rail.

Moreover, this study highlights the need for further research to understand the limitations of call-playback surveys and to identify additional monitoring techniques that can be used in combination with call-playback to provide a comprehensive understanding of banded rail ecology, behaviour, and distribution. This will ultimately lead to more effective conservation efforts aimed at protecting the banded rail and its habitat in the upper Waitemata Harbour and beyond. Overall, this study can contribute to the development of more targeted and effective conservation strategies for the banded rail and other threatened species in tidal mangrove and marsh habitats and help ensure the long-term viability of these important ecosystems.

CHAPTER 5

General Discussion and Comparison of Monitoring Techniques

5.1 GENERAL DISCUSSION

In this thesis, the primary research objective was to evaluate the effectiveness of three different monitoring techniques for detecting and monitoring banded rail populations. The monitoring techniques tested in this study included footprint surveys, camera trapping, and call-playback surveys. The methods used for each chapter of this thesis were tailored to the specific research questions and objectives. Presence/absence count data collected through each of the three monitoring techniques were analysed, and the results provided important insights into the effectiveness of these methods for monitoring banded rail populations. This chapter will discuss the findings of each study and their implications for banded rail conservation.

The findings of this study have important implications for the field of conservation biology, particularly for the monitoring and management of banded rail populations. Footprint surveys were found to be a reliable tool for detecting banded rail presence/absence in wetland habitats and can provide valuable inventory information and trends over time. Camera trapping was also effective in monitoring the behaviour and habitat use of banded rails in mangrove habitats, providing insights into banded rail behaviour and movement patterns. However, call-playback surveys were found to have limitations as a standalone monitoring technique for banded rails in tidal mangrove and marsh habitats.

In the larger context of monitoring techniques for species conservation, this thesis contributes to the growing body of research that emphasizes the importance of using a combination of monitoring techniques to gain a comprehensive understanding of a species' ecology, behaviour, and distribution. Overall, the findings of this thesis provide valuable information for the conservation of banded rails and can inform future management strategies for this species.

5.2 COMPARISON OF MONITORING METHODOLOGY

In this thesis, I assessed the effectiveness of three monitoring techniques for detecting the presence of banded rails: footprint surveys, camera trapping, and call-playback surveys. Each technique had its strengths and weaknesses.

Footprint surveys were an effective technique for detecting the presence of banded rail at 15 out of 20 survey sites, and identifying factors that influence footprint distribution. The results indicated that the size of mangrove habitats, the presence of freshwater, and substrate quality were significant predictors of banded rail footprint frequency. However, this technique only provided information on the presence of banded rails and did not provide data on other aspects of the species' ecology, behaviour or population density.

Camera trapping was also an efficient technique for detecting banded rails, and it confirmed their presence at 7 of 9 survey sites. The method also identified significant predictors of banded rail capture, such as freshwater availability and predator presence. However, camera trapping requires high investment, can be labour-intensive, and the detection rate may vary depending on the site and camera placement. Therefore, it might be less effective when employed in long-term monitoring plans for the banded rail, but could be used to assist alongside other monitoring methodologies as it provides valuable information on behaviour.

Call-playback surveys were moderately effective in detecting the presence of banded rails. While this technique recorded some vocalizations at a few sites, the majority of sites recorded few or no vocalizations. These false absences may have been due to the limitations of this method, as other monitoring techniques such as camera trapping and footprint surveys had confirmed banded rail presence at the same sites in previous chapters. Call-playback surveys could be useful in conjunction with other monitoring techniques to confirm the presence of banded rails, but its effectiveness may vary depending on site conditions, such as habitat type and noise pollution.

Overall, each technique has its strengths and limitations. Footprint surveys are useful for identifying factors that influence banded rail distribution, while camera trapping provides valuable information on behaviour. Call-playback surveys can be useful in conjunction with other monitoring techniques, but their effectiveness may vary depending on site conditions. It is essential to use multiple techniques in long-term monitoring plans to obtain a comprehensive understanding of the species' ecology and population dynamics.

5.2.1 Comparing Monitoring Methodologies Using Statistical Analysis

To determine the statistical significance of differences between the three monitoring techniques, I conducted an ANOVA test, which allowed me to test whether there were any significant differences in the means of the different monitoring techniques. I then used Tukey's multiple comparisons of means HSD test to perform pairwise comparisons between the different monitoring techniques. This test was chosen for its suitability in comparing all possible pairs of means in the study while controlling the family-wise error rate at a 95% confidence level. By employing these statistical methods, a robust comparison of the effectiveness of the three monitoring techniques for detecting banded rails in the upper Waitematā Harbour was achieved.

The results of my analysis demonstrated significant differences in the detection of banded rails between the three monitoring techniques (F-value (2,27) = 5.25, $P = 0.01$) (Table 5.1).

Table 5.1: Mean number of detections, standard deviations, and sample sizes for each monitoring technique.

Monitoring Technique	Sample size	Mean Number of Detections	Standard Deviation
Footprint Surveys	20	42.9	13.6
Call-playback Surveys	17	32.6	12.4
Camera Traps	9	24.1	9.6

The Tukey HSD test revealed significant differences in detection rates between footprint surveys and camera traps ($P = 0.01$), and between footprint surveys and call-playback surveys ($P = 0.001$), indicating that footprint surveys were significantly more effective in detecting the target species compared to the other two techniques. However, there was no significant difference between call-playback surveys and camera traps ($P = 0.89$).

To account for the issue of multiple comparisons and minimize the likelihood of a Type 1 error (false positive), pairwise t-tests with Bonferroni correction were conducted using the pairwise.t.test() function in R. The pairwise comparison results indicated a significant difference in detection rates between footprint surveys and camera trapping ($P = 0.01$), emphasizing the superior efficacy of the footprint technique in detecting banded rails compared to camera trapping. However, no significant difference in detection rates was observed between call-playback and camera techniques ($P = 1.00$).

It is essential to acknowledge differences in sample sizes between the monitoring techniques, which could potentially influence the results. However, these differences were considered in the statistical analysis. Specifically, ANOVA and Tukey's HSD test were employed to test for significant differences in means between the monitoring techniques. Additionally, pairwise t-tests with Bonferroni correction were conducted to account for multiple comparisons. While it is generally recommended to have equal sample sizes for each group in ANOVA, unequal sample sizes can be accommodated with the use of appropriate statistical methods. Nonetheless, caution should be exercised when interpreting the results, and further research with larger sample sizes may be necessary to validate the findings of this study.

The effectiveness of each technique may be influenced by various factors, including the target species, study area characteristics, and the specific methodology used. The limited application of camera trapping at only 9 out of the 20 sites may have affected the accuracy of the comparison between the three techniques. Nonetheless, the study’s findings offer crutial insights into the comparative effectiveness of different monitoring techniques for the target species in the study area, informing future conservation efforts.

Overall, my findings suggest that different monitoring techniques may have varying levels of effectiveness for different target species, and that a multi-method approach may be necessary to accurately monitor and conserve biodiversity. Specifically, in my study area, footprint surveys yielded the highest banded rail detection rates and may be the most effective monitoring technique for detecting the presence of the target species.

While statistical analysis provides valuable insights into the effectiveness of different monitoring techniques, it is important to consider other factors when evaluating their practicality and suitability for conservation management. Footprint surveys and call-playback surveys are likely to be more practical, cost-effective, and time-efficient than camera trapping, which requires expensive equipment and extensive manual sorting of data. However, camera trapping can provide valuable information on banded rail behaviour, ecology, and habitat use that the other techniques cannot. The trade-off between these advantages and costs should be carefully evaluated when selecting the most appropriate technique. Additionally, ethical considerations are important to ensure the welfare of birds and minimize adverse impacts on the environment. Call-playback surveys require careful consideration of the potential impacts on birds, while footprint surveys and camera trapping are passive techniques that have little impact. Therefore, a multi-method approach that considers practicality, cost, ethical considerations, and statistical effectiveness is likely the most suitable for banded rail monitoring and conservation efforts.

5.2.2 Comparison of Monitoring Methods at a Subset of Sites

To further assess the effectiveness of the monitoring methodologies, I compared the detection of banded rails using footprint surveys as the standard method at 9 selected sites. The comparison assessed whether camera trapping and call-playback surveys detected banded rails at the same locations where footprint surveys were conducted. The selection of these 9 sites was due to the availability of camera trapping equipment and time constraints that limited the number of sites that could be included in the study. Consequently, these 9 sites allowed for the testing of all three monitoring methodologies.

The results showed that all three methods detected banded rails at Whenuapai Village, Landing B, and Kauri Point Domain. Footprint surveys detected banded rails at 8 out of the 9 sites, confirming their effectiveness (Table 5.2). Camera trapping was effective at 7 out of 9 sites, while call-playback surveys were effective at only 3 out of 9 sites. At four sites, both footprint surveys and camera trapping detected banded rails, while call-playback surveys did not. At Lancaster Road, footprint surveys detected banded rails in all three plots, while camera trapping and call-playback surveys did not detect any. At Herald Island, none of the three monitoring techniques detected banded rails.

Table 5.2: Comparison of banded rail detection using footprint surveys, camera trapping and call-playback surveys at 9 sites in the upper Waitematā Harbour. Detection status is shown for each plot using each methodology.

Site	Footprint surveys	Camera trapping	Call-playback surveys
Whenuapai Village	Detected	Detected	Detected
Landing B	Detected	Detected	Detected
Kauri Point Domain	Detected	Detected	Detected
Riverhead	Detected	Detected	Not detected
Summerset	Detected	Detected	Not detected
Oratau Place	Detected	Detected	Not detected
Wharepapa Reserve	Detected	Detected	Not detected
Lancaster Road	Detected	Not detected	Not detected
Herald Island	Not detected	Not detected	Not detected

Overall, the results suggest that footprint surveys and camera trapping are more effective in detecting banded rails compared to call-playback surveys. However, the choice of the most appropriate monitoring method should be based on the specific research question and the ecological characteristics of the study area. The limitations of each technique should also be considered. Footprint surveys rely on the presence of footprints, which may not be present if the substrate is too flooded or if banded rails are avoiding that particular area. Camera trapping requires banded rails to cross a specific point to trigger the camera, which may not happen if banded rails are avoiding that area or if there are limited camera placements. Call-playback surveys may be affected by environmental conditions or variations in the calls used. Therefore, the choice of the most appropriate monitoring method should be based on the specific research question and ecological characteristics of the study area.

5.3 LIMITATIONS OF THIS RESEARCH

There were several limitations to this study that could impact the interpretation of the results. One of the major limitations was that camera trapping was only conducted at 9 out of the 20 study sites due to resource and time constraints. This may have limited the accuracy of the comparison between the three monitoring techniques. In future studies, it would be beneficial to conduct camera trapping at all study sites to ensure a more accurate comparison. Additionally, there may have been confounding factors that influenced the findings, such as weather conditions or variations in the behaviour of the target species. These factors were not directly measured or controlled for in my research, and future studies should consider collecting more detailed data on environmental conditions and species behaviour to better understand how these factors may influence the effectiveness of different monitoring techniques.

Timing of surveying is an important consideration when comparing the effectiveness of different monitoring techniques. In this study, each survey technique was tested at a different time of the year. Footprint surveying took place after the banded rail breeding season, camera trapping occurred just prior to the onset of the breeding season, and call-playback surveys were tested mid breeding season. This variation in timing could be a limitation of this research, as it makes it difficult to compare the detection rates of the different techniques directly. Therefore, future studies should aim to further test each of the techniques during different times of the year to determine if the timing of surveys affects their effectiveness. For example, it would be important to determine if call-playback surveys are reliable outside of the breeding season when banded rails may not be as vocal. Additionally, deploying cameras during the breeding season could provide further insights into banded rail breeding behaviour. It would also be interesting to determine if the timing of surveys affects the effectiveness of footprint surveys. For example, banded rail habitat use may change seasonally, and this could impact the detectability of footprints.

It is important to note that the research in this thesis was conducted in a specific study area, and the effectiveness of different monitoring techniques may vary depending on the characteristics of the study area and the target species. Therefore, my findings may not be generalizable to other areas or species. This is particularly relevant for banded rails, as they inhabit a range of habitats across New Zealand, and the effectiveness of monitoring techniques can vary depending on the habitat type. For instance, banded rails in the study area of this thesis primarily inhabit coastal mangrove forests, which are different from the wetlands without mangroves that banded rails in other areas of New Zealand inhabit. Banded rails can also be found in other coastal habitats, such as salt marshes, and in freshwater wetlands and grassland habitats (Elliot, 1987). Thus, the effectiveness of monitoring techniques can vary depending on the specific habitat type and location. Future research should investigate the effectiveness of different monitoring techniques across a range of habitats and locations to provide more comprehensive recommendations for conservation efforts.

5.3.1 Estimating Banded Rail Population Density: Methodological Limitations and Considerations

Regular monitoring of banded rail population density and presence/absence is critical for their conservation. By detecting changes in abundance and site occupancy over time, management decisions can be informed to prevent declines or extinctions. Additionally, monitoring presence/absence in different areas can identify important habitats and inform conservation efforts such as habitat protection or restoration projects. However, accurately determining population density using footprint surveys, camera trapping, and call-playback surveys can be limited by potential biases and limitations (MacKenzie et al., 2002; Williams et al., 2002).

Footprint surveys can be used to determine the presence and relative abundance of banded rails in an area, but they may not be the most effective method for determining population density. This is because the accuracy of footprint surveys in estimating population density can be affected by several factors such as variations in the frequency and quality of footprints, the age of footprints, and the ability to distinguish between different individuals based on their footprints. Additionally, the effectiveness of footprint surveys can be influenced by the habitat type and environmental conditions, such as rain, that can affect the visibility and persistence of footprints (Alström et al., 2015)

Other methods such as camera trapping and call-playback surveys may provide more accurate estimates of banded rail population density by providing direct evidence of the number of individuals present in an area. However, these methods may also have limitations and potential sources of bias that should be considered when interpreting the results. For example, camera traps may not detect all individuals due to variations in behaviour or positioning, while call-playback surveys may overestimate the number of individuals by attracting responses from neighbouring territories (MacKenzie et al., 2002). Therefore, caution should be taken when interpreting the results of this study as a measure of population density.

5.4 CONCLUSIONS AND IMPLICATIONS FOR THE FUTURE

This thesis was able to provide an inventory of the presence/absence of banded rail, as well as identify areas of significant banded rail habitat around the upper Waitematā Harbour, using a range of monitoring techniques. Overall, the results of this thesis suggest that a combination of monitoring techniques is necessary for gaining a comprehensive understanding of the ecology and behaviour of banded rails. Footprint surveys were found to be a reliable and cost-effective method for detecting the presence of banded rails, while camera trapping provided valuable insights into their behaviour and habitat use. Call-playback surveys were found to have limitations as a standalone technique for banded rail monitoring.

The statistical analysis comparing the effectiveness of the three monitoring techniques revealed that footprint surveys were significantly more effective than camera traps and call-playback surveys in detecting banded rails. However, it is important to note that each technique has its strengths and limitations, and a combination of techniques is necessary for gaining a comprehensive understanding of the species ecology and behaviour.

The findings of this thesis have significant implications for conservation practice and policy. Specifically, this thesis highlights the importance of considering the effectiveness of different monitoring techniques when developing and implementing species conservation strategies. The results suggest that incorporating the footprint search technique may improve the accuracy of monitoring efforts and aid in conservation planning. However, a multi-method approach may still be necessary to account for the potential limitations of each technique. Moreover, given the significant differences in effectiveness among the three monitoring techniques studied, it may be necessary to reconsider the use of camera traps as a primary method for monitoring wetland species, especially when more effective methods such as footprint surveys are available. Finally, this thesis found that the call-playback technique was equally effective as camera trapping, suggesting its potential as an alternative monitoring method. It is crucial to carefully evaluate the trade-offs and suitability of different techniques before selecting the most appropriate method for a specific study.

Consistent and long-term monitoring of banded rail is crucial for understanding population trends and identifying the possible agents of decline. This information can then inform adaptive conservation management strategies to protect these populations. To build on this research, future studies should explore other wetland species and examine the efficacy of different monitoring methods. Future studies should also investigate the use of acoustic sensors and eDNA as options for monitoring banded rails in New Zealand. It is essential to develop standardized protocols for multiple monitoring methods to improve the effectiveness of conservation strategies. The difficulty in monitoring banded rail populations makes this research valuable not only for conservation efforts in the study area but also for wider populations of banded rail and related cryptic wetland species overseas.

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APPENDIX

Appendix A: Sample field sheet for recording footprint surveys.

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1

UPPER WAITEMATĀ HARBOUR BANDED RAIL FOOTPRINT SURVEY SHEET 2022

Site Name: ______________________________
Survey No. ____________ Date: __________
Surveyor/s: ______________________________
Low tide: __________ High tide: ____________
Start time: ___________ End time: ____________
Total time spent surveying: ____________________

Weather Conditions (taken from cellphone weather app)			
Temperature (°C)	Wind (km/h)	Rainfall (mm)	Other

Footprint direction key:

Direction	Code
Towards sea	1
Towards land	2
Other	3

Other notes (e.g. incidental sightings, pest control, habitat details): ____________________________
____
____
____

Footprint search:

Plot number	Print ID	Coordinates		Quadrat/ Transect? (Leave blank if neither)	No. of prints	Direction/s of prints	Substrate condition (Excellent =2, Good =1 or Poor =0)	Vegetation type and height (Height = small, medium or mature mangroves)	Notes (Print direction breakdown for Quadrats)
	ID1								
	ID2								
	ID3								
	ID4								
	ID5								
	ID6								
	ID7								
	ID8								
	ID9								
	ID10								
	ID11								
	ID12								
	ID13								

Appendix B: Camera trap results: total photos and videos, blank captures, and banded rail sightings during study period

Site	Number photos	Number videos	Total photos/videos combined	Blank photos/ videos	Animal photos/ videos	Banded rail photos/videos
Summerset (Pilot site)	526	0	526	511	15	9
Herald Island	798	220	1018	1008	10	0
Lancaster Road	4390	743	5133	5095	38	0
Landing B	2017	399	2416	2267	149	71
Oratau Place	2946	622	3568	3542	26	11
Riverhead	355	118	473	467	6	2
Wharepapa Reserve	423	127	550	451	99	11
Whenuapai Village	838	222	1060	984	76	32
Kauri Point	11183	951	12134	12040	94	85

Appendix C: Approval letter from the Massey University Animal Ethics Committee regarding the call-playback study

Saturday, March 25, 2023 at 13:49:21 New Zealand Daylight Time

Subject: [AE011] - Notify Applicant Application Approval AEC 22/48
Date: Thursday, 29 September 2022 at 17:09:02 New Zealand Daylight Time
From: animalethics@massey.ac.nz
To: J.J.Weihong@massey.ac.nz, Indi.Mallinder-Capamagian.1@uni.massey.ac.nz
CC: animalethics@massey.ac.nz

Dear A/Pro Weihong Ji,

Link to the application

AEC 22/48
Testing call-playback surveys as a monitoring technique for Banded Rails (Moho pererū) in the Upper Waitematā Harbour

Your application was considered by the Animal Ethics Committee at its meeting held on 16/09/2022 and was granted approval to proceed.

Approval for ongoing research, testing or teaching procedures must be resubmitted for consideration at least every three (3) years.

Note that any proposed change to your application must be communicated to the Committee prior to its implementation (see sections 3.8.1-3.8.2 of the Code of Ethical Conduct).

Yours sincerely

Massey University Animal Ethics Committee

Appendix D: Spectrograms of the three different banded rail calls used in call-playback surveys, with call type number indicated on the left (1, 2, and 3). Spectrograms were obtained using Raven sound analysis software from recordings uploaded to the software (Cornell Lab of Ornithology, 2021).