Hidden in the Wetlands: Evaluating Playback Effectiveness and Wetland Preferences of the Spotless Crake

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Abstract:

The current knowledge about the cryptic wetland bird Spotless Crake (*Zapornia tabuensis*) is very limited, particularly in relation to its habitat preferences and optimal survey methods. This study aimed to address these gaps by conducted targeted acoustic surveys alongside detailed vegetation mapping and analysis across a range of wetlands in the Manawatū-Whanganui region, New Zealand. Call playback surveys were conducted to investigate factors influencing detection probability and calling rates using generalised linear mixed models to evaluate the effects of environmental and survey variables. Vegetation composition and structure were analysed to investigate associations between habitat characteristics and crake presence. Findings indicate that spotless crake are more likely to occur in wetlands supporting dense fringing vegetation that is dominated by tall emergent species, and also that some habitat flexibility was observed. Detection probability was influenced by both temporal and environmental factors, which underscores the requirement for standardised survey protocols. This study provided invaluable insight into the ecology and monitoring of Spotless Crake, and broader implications for the conservation of other cryptic, wetland-dependent species.

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Table of Contents

Table of Figures

Table of Tables

Chapter 1 – Monitoring Wetlands: Vital, Vulnerable, and Vanishing

Wetlands are vital for both ecosystems and communities supporting biodiversity and delivering essential ecological functions. These habitats purify water, reduce flooding, and pollution and act as carbon sinks, forming a critical transitional zone between land and water. In New Zealand, wetlands are home to many native and threatened plant and animal species. However, these habitats have been heavily degraded primarily due to habitat destruction, introduced pests, and ongoing human activity. Once covering approximately 10% of New Zealand's land area, wetlands have undergone significant loss, severely impacting the species that depend on them.

Reports document the loss of wetlands in New Zealand both prior to and following European settlement. Most of New Zealand's wetlands began forming around 18,000 years ago (McGlone 2009). When Māori arrived in the 13th century, wetlands covered roughly 1% of the landscape. According to Māori land-use practices, such as the removal of woody vegetation and deforestation of catchments possibly led to the creation of new wetlands in drier regions promoting the development of lowland fens and lagoons. In contrast, European colonisation brought widespread wetland drainage, logging, and fire which caused largescale wetland destruction (McGlone 2009). Today, wetland loss continues due to land conversion and invasive species, both of which degrade habitat quality and reduce the area of functional wetland ecosystems.

According to Robertson (2018), comprehensive environmental legislation introduced after the 1990s has helped curb the rate of wetland degradation. Before these protections were enacted, wetland drainage was widespread and many species reliant on these ecosystems were significantly impacted. Of the 32814 wetlands examined, 3452 had been lost and 3943 were at risk. The average rate of wetland loss was 0.5% per year, increasing to 10% when partially drained wetlands were included. The primary driver of this loss was agricultural development.

In 2021, Manaaki Whenua Landcare Research revised national wetland extent estimates using two datasets: Waters of National Importance (WONI) and the New Zealand Land Cover Database (Dymond 2021). The study estimated that freshwater wetlands now cover approximately 249 214 hectares, just 10.08% of their historical extent. This represents a reduction of at least 5954 hectares since 1996.

Understanding how species respond to habitat degradation—both passively and actively—is essential for effective monitoring and conservation. Active responses such as changes in movement patterns or vocal behaviour, e.g., reduced calling in degraded environments, can make species more difficult to detect using standard methods (Duquette 2021). Passive responses such as population decline or reduced site fidelity may further obscure presence in heavily modified landscapes. These behavioural and ecological responses complicate efforts to monitor wetland species accurately, particularly those that are cryptic or acoustically active. Consequently, targeted monitoring techniques such as acoustic surveys or vegetation-based habitat assessments must account for both the presence of suitable habitat and the behavioural tendencies of focal species to ensure reliable detection and conservation outcomes (Atkinson 2022).

Biodiversity Monitoring Challenges and Conservation of Cryptic Wetland Birds in Aotearoa

Wetlands are ecosystems that support high biodiversity by creating conditions conducive to the survival of many unique species. However, research into the ecosystem structure of New Zealand's wetlands has been relatively scarce compared to that on rivers and lakes (Sorrell 2004). Wetland-dependent species such as invertebrates, microbial flora, fish and birds remain understudied, resulting in gaps in our understanding of the impact of wetland loss in Aotearoa. Among these wetland-dependent birds are species such as Australasian bitterns (*Botaurus poiciloptilus*), spotless crakes (*Porzana tabuensis*), and various waterfowl species, many of which are considered cryptic and difficult to monitor.

The Australasian bittern is a critically endangered wetland bird known for its highly cryptic nature due to inconspicuous plumage. Bitterns are distributed across New Zealand, with research on ten male bitterns in Hawke's Bay indicating their use of a network of wetlands within a 15 km radius on a seasonal basis (Williams 2018). Preferred habitats for spotless crakes include raupō, bulrush creek areas with cover, and rank grasslands. As key indicators of wetland health, bitterns encounter significant challenges due to ongoing wetland loss. Habitat destruction and degradation pose major threats to their survival resulting in instances of starvation and low reproductive success (Williams 2025).

The spotless crake and marsh crake (*P. pusilla*) are wetland birds found across New Zealand. Spotless crakes are listed as Nationally Vulnerable by the New Zealand Department of Conservation (2025) while marsh crakes are considered At-Risk Declining. Marsh crake is a subspecies of Baillon's crake (*P. pusilla*) that is distributed throughout Europe and Asia, Africa, New Guinea, Borneo, Australia and New Zealand (Fitzgerald 2023). In New Zealand, they are mostly located in the South Island (eBird 2025). Marsh crake have been recorded in a wide variety of wetlands, especially those featuring *Carex secta* and raupō (*Typha orientalis*). Spotless crakes, however, are distributed throughout the North Island and are rare in the South Island. They have also been found on Raoul Island, Meyer Islets, Great Barrier, Three Kings, Poor Knights, Tiritiri Matangi, and Motuora Islands (Higgins 2025). Spotless crake favour wetlands that feature dense emergent vegetation, particularly raupō, but have adapted to various habitats including dry forests on offshore islands.

The Department of Conservation (DOC) is developing survey methods and restoring wetlands, identifying key habitats, and measuring the impact of conservation efforts. Regional and District councils are responsible for the protection and restoration of wetlands throughout New Zealand. These councils write and follow their own legislation surrounding responsibilities around wetlands. Councils throughout New Zealand, along with the Department of Conservation, prioritise protecting high-value conservation areas to enhance biodiversity and recreation.

Designing Effective Monitoring Strategies for Elusive Wetland Birds

To conserve species effectively, understanding monitoring techniques is crucial. Monitoring plays a fundamental role in wildlife conservation, providing critical insights into species presence, population trends and habitat use. For cryptic species like the spotless crake, monitoring is often the first essential step toward effective conservation as their elusive nature makes them difficult to study through traditional observation. Regular monitoring enables the early detection of population declines or environmental threats, helps identify key habitats, and provides the data needed to evaluate and refine management strategies. Furthermore, it contributes to a broader ecological understanding by revealing how species interact with their environment and respond to change. Ultimately, accurate and ongoing monitoring is essential for making informed targeted and adaptive conservation decisions.

Monitoring is a fundamental component of ecological research and conservation management. At its core, monitoring aims to provide information on the status and trends of species or ecosystems, enabling informed decisions about management protection and restoration. Ideally monitoring would allow us to estimate population sizes track trends over time assess habitat use or evaluate the success of conservation interventions. However, these aims are not always achievable particularly when dealing with species that are elusive, rare, or inhabit difficult environments.

Each method provides a different lens through which we observe wildlife and each carries trade-offs between effort, accuracy, invasiveness and practicality. Thus, careful consideration must be given not only to the choice of method but also to the specific objectives of monitoring. Vocalisation-based surveys are particularly effective for cryptic bittern species, yet their reliability is highly dependent on temporal and environmental factors. The Australasian bittern's calling peaks in early spring and notably one hour before sunrise, with a second rise soon after sunset (Williams 2018). Rain decreases calling rates by about 19%, while a visible moon increases them by over 50% (Williams 2018, Ottenburghs 2019). By starting from the broader principles of ecological monitoring and narrowing down to the specific challenges and advantages of acoustic methods for cryptic species we can better understand how and when these tools are most appropriately applied. This framing is essential for interpreting the reliability of playback responses and for designing robust surveys that provide meaningful conservation insights for species like the spotless crake.

A key consideration when designing a monitoring programme is what information is realistically attainable. For species that are conspicuous and accessible, detailed population censuses may be possible. However, in many cases, particularly with cryptic species inhabiting complex densely vegetated or inaccessible environments, monitoring efforts are constrained to less detailed indicators such as presence-absence data or relative activity levels. These limitations shape not only what questions we can ask but also what methods are suitable.

For example, presence-absence surveys may be the only feasible option in wetlands dominated by dense vegetation where direct observation of individuals is unlikely. In such cases, acoustic surveys, whether passive or interactive, offer a powerful alternative particularly for species that rely heavily on vocalisations for communication. Many wetland birds including Australasian bitterns and spotless crakes fall into this category. However, even acoustic methods have their constraints. Bittern call counts, for instance, often rely solely on the detection of booming males, excluding females and nonvocal individuals from the data and potentially skewing interpretations of population status (Williams 2024).

Monitoring marsh birds is challenging due to the unique characteristics of the birds and of wetlands. Researchers use various methods such as call surveys, listening surveys, automated recorders and playback surveys, each with its advantages and limitations based on species and external factors like weather and human interference. Call surveys can be passive or active. Passive call surveying involves researchers recording animal vocalisations without eliciting responses, causing minimal disturbance and providing reliable data without influencing behaviour. However, it may be less effective when birds are not vocalising. Active call surveying uses recording devices to elicit vocal responses often succeeding where passive surveys fail (Ali 2018).

Monitoring Cryptic Wetland Birds: A Multifaceted Approach to Conservation

Monitoring a range of taxa is essential for identifying threats, evaluating conservation outcomes, and informing adaptive management strategies. This is particularly true for cryptic or nocturnal species where visibility is low and direct observation is challenging. The goals of monitoring may vary—from assessing presence or absence to estimating abundance or understanding movement patterns—but the choice of method must reflect the ecology of the species and the complexity of the habitat.

Recent work has further developed the role of footprint surveys in complex wetland habitats. Jacques de Satgé's PhD research at Massey University (2023), for example, explored footprint-based detection and camera traps to investigate banded rail (*Hypotaenidia philippensis assimilis*) movements between mangroves and saltmarshes. His work demonstrates the versatility of passive monitoring techniques in challenging environments and underscores the potential for footprint-based surveys to reveal spatial habitat use by cryptic species.

In terrestrial ecosystems footprint-based methods offer a useful low-cost tool for monitoring. These include traditional footprint tracking surveys and tracking tunnels which are devices designed to capture footprints of small animals that pass through them. While often used for rodents, tracking tunnels can also detect lizards and insects and their effectiveness varies depending on the behaviour of the target species (Smith 2017). In New Zealand, footprint surveys have even been used for cryptic bird species such as banded rails in saltmarsh environments (Elliott 2018), highlighting their broader applicability.

Monitoring mammal populations, particularly invasive species, remains a critical component of conservation in New Zealand. Introduced predators such as stoats (*Mustela erminea*) and rats have had devastating impacts on native bird populations. In this context, reliable monitoring tools are essential for evaluating the effectiveness of pest control. Smith and Weston (2017) compared artificial nests, tracking tunnels, and camera traps in monitoring stoats, concluding that artificial nests had the highest detection rate and that less conspicuous methods may be more suitable for elusive mammals. Similarly, Anton (2018) evaluated remote cameras across 40 sites in Wellington and found them superior to tunnels for detecting hedgehogs and rats though tunnels were better at recording mice.

While tracking tunnels and camera traps are often associated with mammalian monitoring, the underlying principle of detecting species via physical traces can also apply to birds. For example, footprint surveys have proven useful for detecting cryptic rail species and may be particularly valuable in wetland habitats where birds like spotless crake leave subtle signs of presence that can complement acoustic monitoring. These examples highlight that while different taxa may require different approaches, the principles of monitoring, detectability, repeatability, and minimal disturbance remain constant.

Wildlife monitoring is an essential component of conservation management, providing the data needed to assess species status, detect changes in populations, and evaluate the effectiveness of interventions. However, survey methods vary depending on the overarching aim, whether that be presence-absence detection, estimating population size, or tracking population trends over time. It is useful to distinguish between the types of surveys (e.g., presence-absence, population estimation) and the methods used to achieve them (e.g., tracking tunnels, playback surveys, remote cameras).

Presence-absence surveys aim to detect whether a species is present or absent at a site and can be conducted using a range of methods including indirect signs, e.g., footprints, faeces, vocalisations or physical sightings. Tracking tunnels, for instance, are a method used within presence-absence surveys and involve recording footprints of small mammals, reptiles or birds, that pass through an inked tunnel. Playback surveys, another method within the presence-absence framework, are commonly used for cryptic and vocal species like spotless crake, eliciting calls in response to a prerecorded stimulus to confirm presence. While useful, these methods have their limitations —for example they rely on the animal being active, present at the time of survey, or willing to respond vocally.

Much like presence-absence surveys, camera traps offer a highly effective means of detecting species in the field, providing more detailed and continuous data than traditional methods (Bruce 2024). These motion-activated devices are invaluable tools in wildlife research and conservation offering a non-invasive way to monitor animal populations and behaviours. Set up in natural environments, camera traps capture images or videos when triggered by movement making them especially useful for studying elusive or nocturnal species such as the least bittern (*Ixobrychus exilis*) without disturbing their habitat. They enable researchers to gather data on species distribution activity patterns and even breeding behaviour, ultimately supporting conservation efforts and management strategies. Furthermore, advancements in camera trap technology such as infrared sensors and higher resolution cameras have significantly enhanced their effectiveness in capturing detailed and accurate data across diverse environments.

Each method has strengths depending on the ecology of the target species. For example, tracking tunnels are most effective for terrestrial mammals that readily enter such devices (e.g., rodents) but can also detect lizards and insects. They are less suitable for species that avoid confined spaces. For cryptic wetland birds, playback surveys are more suitable as many of these species are not easily seen but may respond vocally to conspecific calls. Graeme Elliott's work in the 1980s and Jacques de Satgé's (2023) more recent research into saltmarsh and mangrove habitats demonstrate how footprint surveys and remote cameras can also be adapted for elusive birds such as banded rail, further broadening the applicability of presence-absence tools.

Ultimately, the effectiveness of any monitoring programme depends on matching the right method to the ecological context and conservation objective. A multifaceted approach using tracking tunnels, playback surveys, remote cameras or other tools can provide complementary insights, thereby supporting informed adaptive management strategies such as those underpinning the Predator Free 2050 initiative.

Call-Response Surveys Enhancing the Monitoring of Elusive and Cryptic Species

Call-response surveys and other vocalisation-based surveys are recognised as highly effective techniques for wildlife surveying. Here, I discuss several advantages of using vocalisations in wildlife surveying.

- Non-Invasive: This method minimally disturbs the species compared to other survey techniques
- Effective for Cryptic Species: Vocalisations eliminate the need for visual observation which is often more challenging with cryptic species
- Seasonal and Behavioural Insights: Vocalisations may provide information on breeding territory and social interactions which often vary seasonally
- Widespread Coverage: Listening surveys or automated call-recorders offer superior effectiveness in wetlands and forests due to the challenges of navigating these habitats and the potential destruction of habitats during physical surveying
- Increased Detection Probability: Vocalisations enhance detection probability especially beneficial for species active at specific times of day
- Improved Monitoring Efficiency: Playback methods enable researchers to monitor larger areas without physical presence, thus increasing data collection efficiency and reducing the labour involved
- Population Estimation: Analysis of vocalisation rates can offer insights into population numbers and trends over time particularly useful for monitoring cryptic species

The least bittern presents significant challenges for monitoring due to its reliance on dense breeding habitats and tall emergent vegetation, which hinder visual observation. Its elusive nature further complicates traditional monitoring methods such as visual surveys. However, techniques like call-response surveys and playback surveys prove useful for detecting the least bittern, as these methods rely on vocalizations rather than direct observation thereby enhancing detection probabilities.

Research by Bogner and Baldassarre (2002) investigated the effectiveness of broadcasting recordings of conspecific vocalizations, and found these surveys to be valuable tools for monitoring least bitterns. The study indicated that response rates varied according to the breeding stage of the bird's nest initiation, incubation, or hatching, with a higher rate of responses (~50%) occurring near nest initiation. Furthermore, the research demonstrated that response rates could serve as an effective method for estimating the true abundance of male least bitterns within a marsh.

Vocalisations are often the most effective—and in some cases the only—method for surveying New Zealand's ground-dwelling birds. All five species of kiwi (*Apteryx* spp.) are nocturnal, cryptic, and spend a significant proportion of their time in burrows, making visual surveys impractical. Kiwi possess unique sexually dimorphic vocalisations and are known to respond to conspecific calls. Kiwi call surveys have been the mainstay of detection work for a long time, having started in 1986 with the Wildlife Service. Kiwi exhibit an uncommon form of acoustic cooperation between sexes as documented by Digby (2013). Dent and Molles (2016) investigated the feasibility of using call-based identification as a long-term monitoring tool for great spotted kiwi (*Apteryx haastii*). Automated acoustic recorders were deployed near the nests of seven breeding pairs from November 2012 to March 2013, with recordings repeated at three nests during the subsequent season September-December 2013. The analysis of temporal and spectral characteristics of the calls demonstrated that vocalisations are highly individualised and temporally stable, enabling researchers to accurately identify individual birds across years. These findings highlight the conservation value of acoustic monitoring and its potential to enhance kiwi population management and long-term monitoring strategies.

The North Island weka (*Gallirallus australis greyi*), an endangered subspecies of rail endemic to New Zealand, has faced significant population declines due to human colonisation impacts such as habitat loss and introduced predators. Currently its populations are largely confined to small isolated areas in the East Cape region (Beauchamp 1998). Due to their secretive nature and preference for dense vegetation, rails are challenging to monitor using traditional visual survey methods. Bramley and Veltman (2000) assessed the effectiveness of call count surveys as a monitoring tool for North Island weka populations within conservation management efforts. Through the application of a Generalised Linear Model, they determined that call frequency was significantly influenced by the listening site and the month of the year. Despite testing various environmental factors, including wind direction, and strength, cloud cover, moon phase, rainfall, and temperature, none demonstrated a significant impact on the number of weka calls recorded. The study revealed that the mean number of calls was highest between December and March with a notable peak occurring in January. These results emphasize the importance of temporal factors in call-based surveys and endorse the use of vocalisation monitoring as an effective method for evaluating the presence and abundance of this endangered rail species.

Vocalisations are essential for monitoring New Zealand's cryptic and endangered bird species serving as an effective tool for tracking population trends and understanding their behaviour. For species such as the Australasian bittern, kiwi, kokako (*Callaeus wilsoni*), and weka, vocalisations provide valuable information regarding their presence territory and breeding activity. For instance, passive monitoring has proven successful in estimating bittern populations, while kokako and kiwi are monitored through call identification. These methodologies are particularly significant due to the challenges posed by these species' secretive nature and preference for dense habitats. By utilizing vocalisations researchers can efficiently gather data on these birds without disrupting their natural behaviours, making it a non-invasive and reliable method.

Seasonality, Behaviour and Effective Survey Design in Wetlands

Effective surveys are fundamental to successful conservation and management efforts, providing essential data to inform decision-making. The accuracy of these surveys directly influences the ability to assess species populations, monitor ecosystem health, and evaluate conservation outcomes. Poorly designed surveys can lead to inaccurate data resulting in misguided policies or ineffective strategies. This is especially true in wetlands where dynamic ecosystems, fluctuating water levels, dense vegetation, and cryptic species present unique challenges. These factors complicate data collection making consistent monitoring difficult and underscoring the need for careful planning and execution particularly when traditional methods are impractical or intrusive for elusive nocturnal or cryptic species.

Seasonality significantly impacts the effectiveness of surveys, especially in wetlands where bird behaviour and habitat use shift in response to seasonal changes. Wetland species such as birds rely on specific seasonal changes for breeding migration and foraging. These changes can lead to shifts in species populations making them more challenging to track. For instance, many wetland birds are migratory and the availability of wetlands for feeding resting and breeding varies seasonally. These fluctuations can cause birds to concentrate in specific areas during abundance, making them easier to observe but disperse during leaner periods making them harder to detect. Seasonal fluctuations in water levels, food availability, and habitat conditions can significantly affect survey accuracy and surveys must account for these changes to ensure reliable data collection (Prajzlerová *et al.* 2025).

Additionally, the time of day plays a crucial role in survey effectiveness. Many species are more active during specific periods such as dawn, dusk, or night which can influence the success of passive surveys like acoustic monitoring camera traps and remote sensing. For example, birds are often more vocal during the early morning or late evening, making acoustic monitoring more effective at these times, whereas during midday their vocalizations may decrease reducing survey effectiveness (Williams 2016). The timing of surveys must be carefully planned to match species activity patterns to capture accurate data.

Studies such as the call-broadcast surveys by Harms and Dinsmore (2014), demonstrate how species responses can vary not just by season but also by time of day. Harms and Dinsmore found that species responses in call-broadcast surveys in pied-billed grebes (*Podilymbus podiceps*), Virginia rail (*Rallus limicola*), and sora (*Porzana carolina*) were higher during the early breeding season compared to the late season. Some species like the pied-billed grebe may show a notable difference in responses based on time of day, while others like the rails are more influenced by seasonality. This variation emphasizes the need to consider both time-of-day and seasonal factors when designing surveys, as different species may respond differently to these factors. Understanding these species-specific patterns is key to improving the efficacy of surveys.

For Ecological Impact Assessments EIAs, incorporating seasonal and temporal factors into survey design ensures more accurate species detection. Wetland species exhibit distinct seasonal behaviours tied to breeding, migration and food availability (Williams 2024). Failure to account for these factors in EIAs could lead to underestimating the presence of species during critical periods potentially resulting in inadequate mitigation strategies. EIAs should incorporate survey timing that aligns with peak species activity to sing crucial ecological features. Moreover, understanding when species are more vulnerable, such as during breeding or migration, helps adjust mitigation measures ensuring minimal disturbance to species at sensitive times.

In addition to seasonal and time-of-day influences, environmental factors such as weather conditions can affect survey outcomes, but modelling factors that influence calling rates allows researchers to adjust counts from sub-optimal conditions – reducing reliance on being in the right place at the right time and improving comparability of monitoring data for cryptic species (Williams 2016). High winds heavy rainfall or dense vegetation may interfere with acoustic recordings or camera trap detections leading to nonresponses that do not reflect true species absence. Furthermore, inadequate survey design—such as insufficient frequency or duration—can result in missed detections especially for elusive or cryptic species. Understanding these variables is essential for interpreting survey results accurately and for mitigating the risk of false negatives where species are present but not detected. Careful planning tailored to the species behaviour and environmental conditions improves survey reliability and helps avoid misinterpretation of data, ultimately supporting better conservation and management decisions.

Tailoring Acoustic Monitoring: Species and Environment Insights from Diverse Ecosystems

Sousa-Lima (2013) conducted a review of over 30 types of autonomous recorders used for passive acoustic monitoring of marine mammals. The study highlighted their effectiveness as cost-efficient tools for detecting presence, estimating abundance, and tracking the spatial and temporal patterns of vocalising species while also noting variation in their capabilities and limitations. However, the performance of these systems depends heavily on the goals of the study, the acoustic environment, ambient noise conditions, and the vocal behaviour of the species in question. For instance, baleen whales which produce low-frequency sounds typically require long-term deployments, sometimes up to a year, with lower spatial coverage and sampling rates. In contrast, odontocetes toothed whales which produce high-frequency sounds require a denser array of ARs with higher sampling rates to ensure adequate detection. This study highlights the importance of tailoring acoustic monitoring systems to the species and conditions of each study to maximize the efficacy of conservation and research efforts. Similar to birds, bats, and amphibians, acoustic monitoring has proven to be a powerful tool for marine mammals particularly when visual surveys are limited by the inaccessibility or vastness of the environment.

Acoustic monitoring has emerged as a highly effective tool for surveying terrestrial mammals, particularly those that are challenging to detect through visual observation. Numerous terrestrial mammals rely on sound for communication, and these vocalisations provide valuable insights into species presence, distribution, and behaviour. Species such as large felines, primates, and even small mammals like rodents and shrews, utilize vocal cues for a variety of functions including territory establishment, warning signals, mating, and maintaining social bonds. Species-specific vocalisations are a valuable resource for conservation research as they can help distinguish between individuals or groups (Blumstein 2011). In habitats where direct observation is challenging—such as dense vegetation or rugged terrain—acoustic monitoring offers a viable alternative particularly for nocturnal cryptic or threatened species (Marques 2013). Additionally, vocalisation data can be used to examine activity patterns across seasons times of day and in response to environmental or anthropogenic factors (Kunc 2016).

Acoustic monitoring techniques are versatile tools that can be applied across various species including birds, bats, amphibians, marine mammals, and terrestrial mammals. These acoustic tools—whether passive or active—offer a non-invasive effective and scalable way to gather data on elusive species. They are particularly valuable when visual confirmation is unreliable or impossible, reinforcing their relevance beyond the avian world. These methods highlight the importance of considering both temporal factors and site-specific conditions when using acoustic monitoring to estimate frog populations as these variables can significantly affect the accuracy and reliability of the data collected. By broadening the application of acoustic monitoring across diverse groups, researchers gain insights into the behaviour distribution and health of various species. This technology is not only nonintrusive but can also be tailored to meet the specific needs of different environments and species offering a powerful tool in conservation and ecological research.

Conclusion: The Role of Wetland Habitat Characteristics in Supporting Cryptic Species and Informing Conservation Efforts in New Zealand

Wetlands require specific vegetation and habitat characteristics to function properly and support specialised wetland species. A study by Ma Cai (Ma 2010) identified several key habitat variables that influence waterbird use of wetlands, including water depth, water level fluctuations, vegetation structure, salinity, topography, food type and accessibility, wetland size, and connectivity. Wetlands are commonly defined as areas with high groundwater tables, characterised by permanent or temporary inundation, or soils with hydric properties (Dawson 2003). Because wetlands provide numerous critical ecological functions and are closely tied to water availability they, and the species that depend on them, are particularly susceptible to the impacts of climate change, human activities, pollution and reclamation, land use changes, and other factors.

In New Zealand, approximately 90% of all wetlands have been drained or lost since human colonisation. This loss is more significant than nearly anywhere else in the world, particularly considering the high number of wetland-dependent species native to New Zealand. The largest remaining wetland complex is located in the floodplains of the Hauraki Plains, however these wetlands have been almost entirely altered or drained through logging the construction of dikes and canals and extensive land drainage (Hatvany 2008).

Wetlands are complex and vital ecosystems that support numerous ecological functions, and their restoration is essential for protecting and recovering New Zealand's native biodiversity and ecological health. Another crucial type of wetland is the peatland ecosystem which plays a significant role as a global carbon sink. In New Zealand, much of the historical peatland area has been drained for agricultural development including significant portions of the country's largest remaining raised peat bog Kopuatai Bog (Goodrich 2017). In light of the current climate crisis, the preservation and restoration of carbon sinks such as peatlands is increasingly important.

Conservation efforts for wetlands in New Zealand face several challenges. Although legislation recognises the necessity of protecting wetlands, many are situated on private properties within agricultural areas complicating their maintenance and management. Regional and district councils are responsible for implementing this legislation and developing regulations to protect wetlands and prevent degradation. Due to variations in council policies the protection of wetlands can significantly differ. Numerous scientists acknowledge the critical importance of wetland conservation and are actively researching methods to enhance conservation and restoration efforts in New Zealand.

The spotless crake is a small, secretive wetland bird native to New Zealand. Historically, it was widespread across the country; however, its distribution has become increasingly fragmented due to habitat loss and predation. In New Zealand, the spotless crake is primarily found in the upper regions of the North Island, while only populations of sparse, isolated communities are in the South Island (Figure 1-1. Notable populations exist on offshore islands, including the Kermadec Islands, Manawatāwhai, Poor Knights Island, and the Chatham Islands. Spotless crakes inhabit wetlands supposedly characterised by dense vegetation that provides cover and nesting sites. These birds are elusive and prefer dense vegetation that makes them challenging to detect, which underscores the importance of targeted monitoring efforts. The spotless crake is classified as "At Risk – Declining" under the New Zealand Threat Classification System, however the true number of birds is unknown.

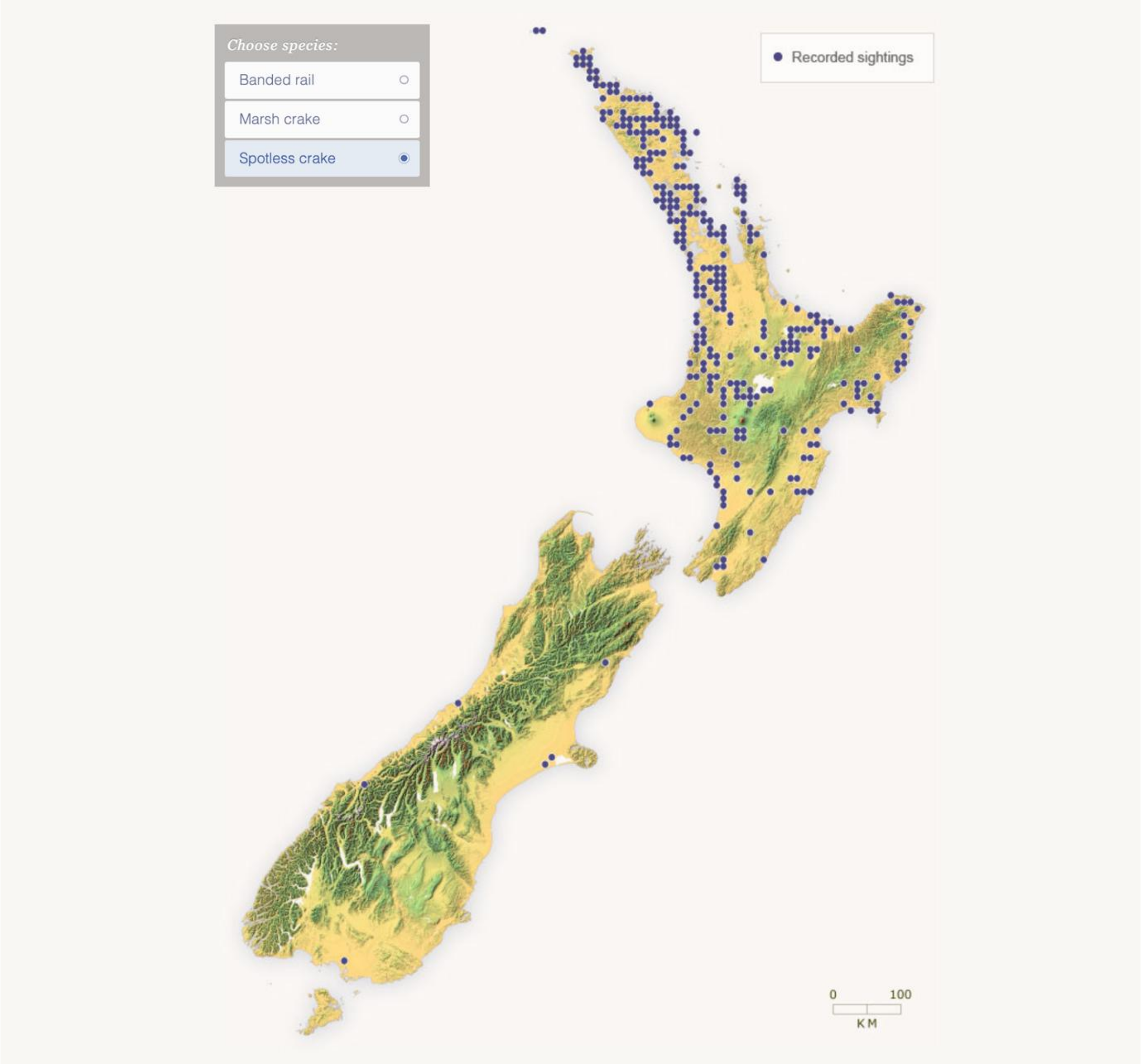


Figure 1-1. Distribution of spotless crake. Source: Te Ara

This thesis aims to address the knowledge gap in monitoring cryptic wetland species in New Zealand, with a particular focus on the spotless crake. Spotless crakes are notoriously difficult to detect due to their elusive behaviour and dense habitat preferences. Vocalisations offer a critical means of detecting this species as they are known to produce distinctive calls—particularly during the breeding season—that can be effectively targeted using playback surveys (Kaufmann 1988, Williams 2016). However, little is known about how frequently these birds vocalise or how environmental conditions influence calling behaviour.

In New Zealand, the distribution of spotless crakes is patchy and largely confined to remnant and restored wetland habitats. Data from platforms such as eBird show that populations are present in select regions including the Manawatū-Whanganui region, where historic records suggest a higher frequency of observations. Understanding the habitat characteristics that support these populations is essential for effective wetland management. Although detailed habitat requirements are not fully understood, spotless crakes are typically associated with wetlands that feature dense emergent vegetation, shallow water, and minimal disturbance.

In this thesis, I use playback-response surveys to document variation in response rates of spotless crakes across a range of wetland sites in the Manawatū-Whanganui region. The key aim of these surveys is to evaluate how environmental factors—such as temperature, time of day, weather conditions, cloud cover and wind speed—affect the likelihood of crakes responding to calls. Habitat characteristics at sites where crakes were confirmed versus those where crakes were not confirmed will be used to test if there are features of wetland sites that are strongly associated with crake presence.

The thesis is structured around two research chapters:
Chapter 2: Environmental influences on playback responses of spotless crakes.
Chapter 3: Silent Signals: Crake habitat clues.
The thesis closes with a General Discussion (Chapter 4).

Chapter 2 - Environmental influences on playback responses of spotless crakes

Abstract

The spotless crake (*Zapornia tabuensis*) is a cryptic wetland bird distributed across Australasia and the Pacific. Its elusive behaviour and preference for dense vegetation complicate ecological study and monitoring. This study aimed to identify how environmental conditions influence crake vocal behaviour to improve detection success during acoustic surveys. Playback surveys were used to evaluate the effects of temperature, time of day, and weather on response probability and call rates. Binomial and Poisson generalised linear mixed models were applied to assess whether and how calling varied across sites. At occupied sites, the probability of detecting a crake in a single survey was ~80%, indicating that two independent surveys provide ~95% confidence of absence. Across all sites, detection probability increased with higher temperature and was highest during early morning and evening, while call rates were suppressed by strong wind or cloud and influenced by light and month. In sites where crakes were confirmed to be present, time of day replaced temperature as the primary predictor, while other environmental factors remained influential. Light intensity had minimal effect, suggesting crake responsiveness is more closely tied to circadian rhythms than absolute light levels. These findings highlight the effectiveness of playback surveys under favourable conditions and emphasise the importance of accounting for environmental variation to reduce false negatives in monitoring cryptic wetland birds.

Introduction

Ecology and Detection Challenges

The spotless crake (*Zapornia tabuensis*) (known locally as pūweto) is a highly cryptic wetland bird belonging to the Rallidae family and it is found across a broad range within the Australasian and Pacific regions. This species is notoriously elusive, inhabiting dense, often impenetrable wetland environments, which contributes to its secretive behaviour and makes it difficult to observe or study. As a result, there remains a significant gap in the knowledge of its ecology distribution and population dynamics. Furthermore, while vocalisations are often used to determine the presence of spotless crakes, how calling and response rates vary with environmental conditions is not well understood. This lack of detailed vocalisation data presents a considerable challenge to researchers seeking to monitor the species effectively and design appropriate conservation strategies.

Playback Surveys and Monitoring Methods

Playback surveys where prerecorded calls are broadcast to elicit responses from wildlife are a commonly used method for surveying cryptic species like the spotless crake. While this technique has proven useful for some species, its application to the spotless crake remains underexplored; calls are routinely used to confirm the presence of crakes, but how these vocalisations vary and whether the likelihood of a response changes under different conditions remain poorly understood. One of the main issues with using playback calls for monitoring is the uncertainty around the reliability and variability of responses. A key challenge is the occurrence of false negatives—instances where a species is present but does not respond to the playback. In such cases, the absence of a response may be misinterpreted as an absence of the species leading to potential underestimates of their true presence and distribution.

O'Donnell and Williams (2015) outlined four core protocols for the inventory and monitoring of Australasian bitterns, building upon techniques used internationally and modifying them for New Zealand's environmental conditions. These protocols were further enhanced by incorporating automatic recording technologies which improved the ability to monitor elusive species across large remote or difficult-to-access wetland habitats.

The adaptability of the DOC protocols allowed for a robust and repeatable survey method that maximised the likelihood of detecting the species, while also capturing the influence of environmental variables on vocal behaviour. Previous studies have highlighted the importance of incorporating time of day into playback survey design to explore potential temporal patterns in vocal activity. For example, Polak and Martin (2005) examined variation in vocalisations of two rail species and found that the water rail *(Rallus aquaticus)* exhibited significantly greater vocal output in the evening compared to the morning whereas the little crake *(Porzana parva)* showed a distinct peak in vocal activity at dawn. Both species demonstrated elevated vocalisations shortly before sunrise and again before sunset. These findings underscore the importance of accounting for diel variation in survey protocols as vocal behaviour can shift considerably throughout the day.

O'Donnell and Williams (2015) outlined four core protocols (presence/absence surveys, distribution surveys, occupancy surveys and relative abundance surveys) for the inventory and monitoring of Australasian bitterns (*Botaurus poiciloptilus*), building upon techniques used internationally and modifying them for New Zealand's environmental conditions. Each of these four protocols are relevant to spotless crake monitoring. Given the similarities in habitat preference, secretive behaviour, and low call rates between bitterns and spotless crake, these bittern methodologies are highly applicable to crakes.

Williams *et al.* (2016) explored how environmental and temporal variables influence natural calling rates of spotless crakes, to improve the reliability of passive call-count monitoring. Their study analysed over 6,000 sound recordings collected from five North Island wetlands during the breeding season and found that natural calling rates varied significantly in response to a range of environmental factors. Seven key variables—time of day, rainfall, cloud cover, windspeed, ambient noise, moon phase, and moon visibility—consistently influenced calling behaviour. Based on these findings, Williams *et al.* recommended conducting surveys during dry, calm mornings or early evenings, when calling activity is most likely. They also highlighted the importance of standardising survey conditions and accounting for influential variables to enhance the accuracy of long-term population monitoring. Additionally, Williams *et al.* emphasised the need for further research into how water levels, breeding stages, and bird demographics influence detectability, to strengthen future monitoring approaches. It is not clear, however, how directly these findings about variation in natural calling rates apply to playback surveys, in which calls are broadcast and responses used to confirm the presence of crakes.

Research Aims and Approach

In this chapter, I investigate the call response behaviour of the spotless crake and examine how call rates vary across different environmental conditions during playback surveys. Unlike natural calling studies, this research specifically focuses on vocal responses elicited through broadcast calls, with the aim of establishing an effective and targeted monitoring method for this cryptic wetland species. Given the species' secretive nature and preference for dense wetland vegetation, reliable detection methods are essential for effective monitoring and conservation. I used playback surveys to examine how environmental variables such as temperature, time of day, wind, cloud cover, light, and month influenced the likelihood of crake detection and the number of vocal responses. This approach allowed me to explore how environmental conditions affect detectability and calling behaviour, with the aim of improving monitoring protocols for this and other cryptic wetland birds.

Methods

Study Area and Site Selection

To investigate the environmental factors influencing spotless crake vocal behaviour, we analysed data from systematic call playback surveys conducted across multiple wetland sites. We employed generalised linear mixed models (GLMMs) to explore how variables such as temperature, time of day, wind, cloud cover, light levels, and survey sequence impacted both the likelihood of detecting vocal responses and the calling rate. Incorporating location as a random effect accounted for spatial variation and repeated measures, enhancing the reliability of our findings. By comparing a suite of candidate models, we aimed to identify the key drivers of vocalisation patterns and improve understanding of the species' detectability under varying environmental conditions.

The research was conducted across 21 discrete wetland sites within the Manawatū-Whanganui region (Table 1), encompassing a broad spectrum of freshwater wetland types including swamps, bogs, oxbow lakes, and constructed wetlands. Wetlands were chosen based on habitat heterogeneity, spatial spread across the region to ensure ecological representativeness, accessibility and, where known, prior evidence of spotless crake presence.

Within each wetland, one to six survey stations were established with a minimum spacing of 100 metres to reduce pseudoreplication and to minimise the risk of double-counting individual birds. Site selection was informed by field reconnaissance and habitat suitability assessments with a focus on identifying areas with dense emergent vegetation, e.g., *Typha orientalis, Eleochari., Juncus*, and native sedges, permanent or semipermanent water and minimal anthropogenic disturbance.

Playback Survey Protocol and Data Handling

Survey Timing and Seasonal Distribution:

Surveys were conducted between September 2024 and February 2025 to capture both pre-breeding and peak breeding vocal behaviour, Although the primary period of vocal activity is expected during spring and early summer/October–January, additional surveys were included before and after this window to evaluate if response rates differed outside the core breeding period. Surveys were conducted at 22 wetland locations, covering a total of 59 sites. Survey effort varied among sites, ranging from a single visit (e.g., Ferry Reserve, Waayer's Wetland) to intensive repeat sampling (up to 18 surveys at Lake Alice and 16 at Koitiaka Swamp and Lake Westmere). Most sites were visited on 2–6 occasions.

Surveys were conducted between 0600 and 2000 hours. Rather than restricting sampling to fixed diel periods e.g., dawn and dusk, survey times were grouped into two-hour intervals e.g., 0600–0800, 0800–1000 etc, enabling a more detailed analysis of calling behaviour across the day. This design allowed for a comprehensive investigation into how spotless crake vocal responses varied temporally supporting a more nuanced understanding of daily activity patterns. The playback device was ideally placed 1 metre above the ground or in a clear location that is not disturbed by vegetation. Device was placed the area of interest, with both ends facing to the left and right of area. The sound was played at maximum volume to ensure consistency across repeats

Table 2-1. Study locations, number of sites within each location, and the total number of playback surveys at each location. Sites are ordered alphabetically.

Unique Locations	**Latitude (ºS)**	**Longitude (ºE)**	**#Sites**	**#Surveys**
Ashhurst Domain Wetland	40.29992062	175.7580036	2	2
Broadlands Wetland	40.244340	175.781522	3	3
Fault Fen Wetland	40.360435	175.802453	3	3
Ferry Reserve	40.46408204	175.2545275	1	1
Kaikai & Operau Wetland	40.54358852	175.2273267	3	5
Karere Lagoon	40.40228912	175.5258025	3	15
Karere Road	40.4060272	175.5371638	1	5
Koitiaka Swamp	40.06957433	175.1354329	4	16
Kuku Beach Rd	40.66408006	175.1646685	2	2
Lake Alice	40.13441912	175.3319183	6	18
Lake Graeme	40.57109364	175.225226	6	6
Lake Omanu	40.45026512	175.2513373	6	12
Lake Papaitonga	40.64401491	175.2250886	2	2
Lake Westmere	39.89472893	174.9989246	4	16
Lake Wiritoa	39.97452476	175.0898539	3	6
Pohangina Luterells Garden	40.17475863	175.7912066	1	1
Pohangina Wetlands Dev	40.17599647	175.7932022	3	6
Pukepuke Lagoon	40.34170821	175.2656641	5	15
Raumai Lagoon	40.21464706	175.7763922	1	2
Waayer's Wetland	40.2091882	176.2129537	1	1
Waikawa Beach	40.69701559	175.1429987	2	2
Woodville Ferry Reserve	40.33588828	175.8169156	3	6

Playback Survey Design:

Playback surveys followed a standardised protocol adapted from the Department of Conservation (DOC) Technical Series 38. The methodology was tailored to suit the ecology and behavioural patterns of the spotless crake, taking into account its cryptic nature low detectability and affinity for dense wetland vegetation. Playback audio consisted of a 5-minute track containing a series of species-specific vocalisations including the ‘pit’, ‘bubble’, ‘harr’, and ‘murmur’ call types, interspersed with 80 seconds of calls in total across 5 bouts with 30 seconds of silence between each to allow time for detection of natural or responsive calls. Tracks were played at a consistent output level using a FOXPRO NX4 facing into suitable habitat. To minimise bias, playback volume and orientation were standardised. At each survey the observer stood motionless during and after playback recording all responses and behavioural cues. A total of 165 surveys were conducted across 65 survey locations within 21 individual wetland sites (Table 1).

Response Data Collection:

Each observed response was recorded in real time using a pre-designed datasheet. Information logged included the type of vocal response, estimated distance and direction from the observer, number of calling individuals, time of response in seconds from start of playback and any associated behaviour, e.g. movement, duetting, overlapping calls. Calls were documented in 10-second blocks for a window of 300 seconds (5 minutes). For each call playback survey, vocal response was recorded as a binary variable (ResponseBinary), where 1 indicated any response and 0 indicated no response. Total calls were the total number of calls detected in the 5-minute survey period.

Environmental Variables and Contextual Data

To assess how environmental and temporal conditions influenced spotless crake vocal activity, several variables were recorded at the start of each survey. These factors were selected based on their potential to affect bird detectability and calling behaviour (summarised in Table 2-2).

Temperature: Ambient temperature was recorded at the beginning of each survey using a Kestrel 3000 handheld digital anemometer. Temperature was treated as a continuous variable.

Cloud Cover: Cloud cover was estimated visually and recorded as an eighths scale, where 0/8 indicates a completely clear sky and 8/8 denotes full cloud cover. Observations were made throughout the survey period, and an average value was used to characterise overall cloudiness during each survey.

Light Level: Light intensity was measured in lux before each survey using a digital light meter (QM1587).

Wind Speed: Windspeed (measured in metres per second, m/s) was recorded at the beginning of each survey using a Kestrel 3000 handheld digital anemometer.

Rain Presence: Rain was recorded as a binary (present/absent) variable based on visual observation and auditory cues at the start of each survey.

Additionally, vegetation and water conditions were recorded in the field. Vegetation composition was assessed using a combination of field observations and existing datasets provided by Horizon Regional Council. Where relevant, water depth and the extent of inundation were estimated visually and recorded.

Table 2-2. Description of environmental variables recorded during spotless crake surveys, including units of measurement and categorical groupings where applicable.

Environmental Variable	**Units of Measurement**
Time of day	Categories: 06:00–08:00, 08:00–10:00, 10:00–12:00, 12:00–14:00, 14:00–16:00, 16:00–18:00, 18:00–20:00
Temperature	Degrees Celsius (°C)
Cloud cover	Scale from 0 to 8 (0 = clear sky, 8 = full cloud cover)
Light level	Lux
Wind speed	Metres per second (m/s)
Date	dd/mm/yy
Month	Calendar month (1-12)
Survey number	Integer (1..2..3)

Analytical Framework and Statistical Modelling

For analysis, the survey data were divided into two datasets: “all sites”, which included data from every location where playback surveys were conducted regardless of crake presence, and “confirmed sites”, a subset including only those sites where spotless crakes were confirmed through acoustic detection. This distinction allowed me to compare the consistency of apparent environmental influences on vocal response across all survey areas and those where crakes were confirmed to be present.

Multiple generalised linear mixed models (GLMMs) were employed to identify environmental predictors of vocal response. Binomial GLMMs were used to assess the effect of environmental variables on whether or not a response was detected during a survey. Poisson GLMMs were used to assess the effect of environmental variables on the total number of calls detected in a survey. Before constructing candidate models, pairwise combinations of the main environmental variables (cloud cover, wind strength, temperature, light intensity, and time of day) were plotted as jittered scatterplots, and relationships tested by Kendall’s tau for ordinal data or Pearson’s correlation tests for continuous variables. Three pairs of variables were significant associated: cloud cover was weakly negatively related to wind speed, light and wind were weakly positively related, and temperature and time of day were strongly positively related (Figure 2-1). When constructing candidate models, temperature and time of day were included together and also separately in models to account for their strong collinearity.

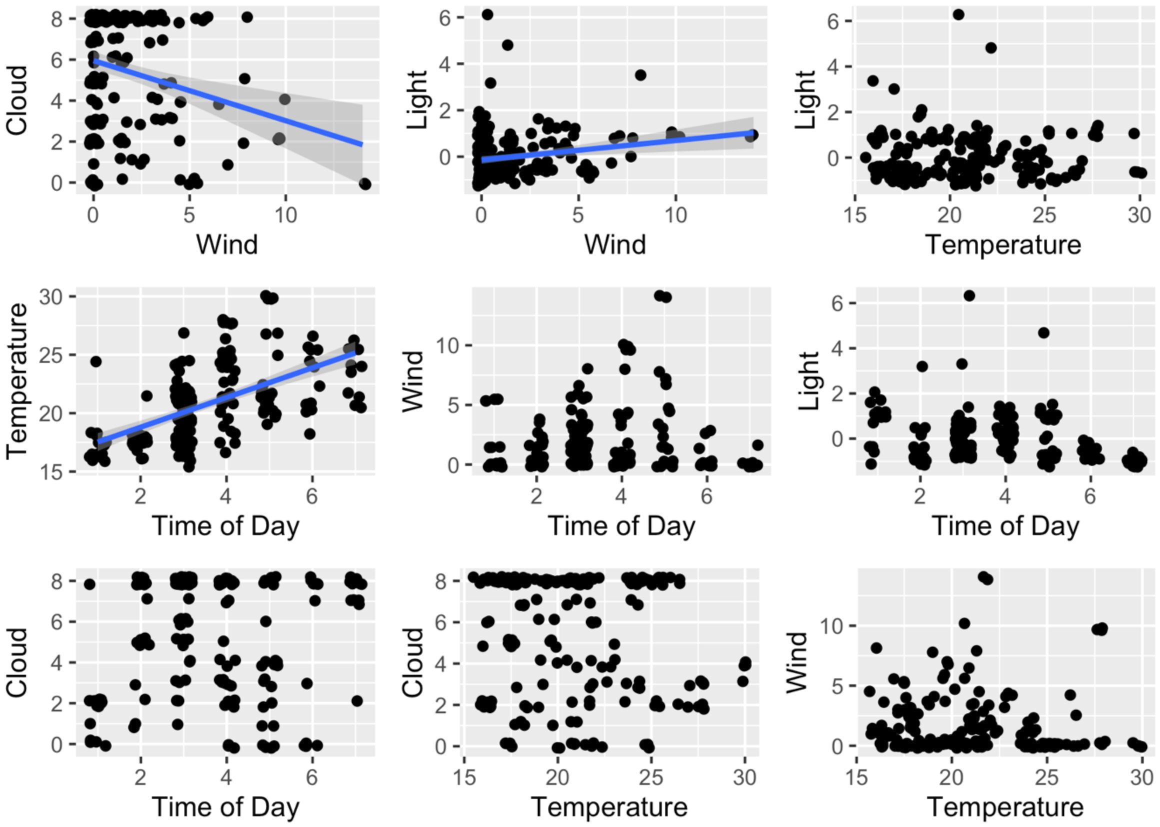


Figure 2-1. Pairwise relationships among environmental variables. Significant associations are shown by regression lines.

Candidate models (Table 2-3) constructed to evaluate the influence of temperature, wind speed, light levels, cloud cover, survey sequence (SURVEYSEQ, whether the survey was the 1st, 2nd, 3rd etc for that site), and month on both detection (binary) and call count (frequency) responses. Models were run using two datasets: the full dataset, which included all survey sites, and a reduced dataset limited to sites with confirmed spotless crake presence. The full dataset represents the full range of survey effort and environmental variation but includes many zero-response locations where crakes may have been absent or they may have remained undetected.

In all models, a random intercept for survey location was included to account for non-independence of repeated measures within sites. Fixed effects tested across the models included ambient temperature, time of day, wind speed, cloud cover, light intensity, survey month, and the order of survey playback. Model complexity was gradually reduced from full models containing all variables to simpler additive combinations and single-variable models. The final model (m22) included only the random intercept and served as a null model for comparison. This stepwise reduction allowed us to identify the most parsimonious models and assess the relative contribution of each variable to detection probability using Akaike's Information Criterion (AIC), with models within 2 AIC units of the 'best' model being considered informative. Model diagnostics included visual inspection of residuals to assess fit and identify outliers or model violations.

Full Models (m1 – m6)

These models included all key environmental and temporal predictors: temperature, time of day, wind speed, cloud cover, light level, survey month, and survey sequence. A random intercept for site was included in all models.

Intermediate Models (m7 – m15)

These models tested smaller combinations of predictors by removing one or more variables (e.g. month or survey sequence) to explore simpler, more focused model structures.

Minimal Models (m16 – m21)

Each model included only one or two predictors (e.g. temperature or time of day) plus the random effect of site, to assess the individual influence of key variables.

Null Model (m22)

This model included only the random intercept for site, with no fixed effects, and served as a baseline for comparison.

In the binomial models, a logit link function was used to assess how environmental covariates influenced the probability of detecting spotless crakes during playback surveys. The logit transformation of the response allowed me to model the log-odds of a detection occurring as a linear function of the covariates. This approach enabled quantification of how each environmental factor affected detection likelihood while accounting for the non-normal distribution of the binary response variable.

To assist in interpretation of the final models, effect plots were generated to visualise the estimated coefficients and their 95% confidence intervals. These plots provide a clear summary of the direction and strength of each predictor's effect on the probability of a spotless crake response, while accounting for the influence of other covariates. Variables whose confidence intervals do not cross zero are interpreted as having a statistically significant effect on detection probability.

Table 2-3. Candidate model structures and predictor variables for Generalised Linear Mixed Models.

MODEL	TEMP	TIME OF DAY	WIND	CLOUD	LIGHT	MONTH	SURVEYSEQ	RANDOM EFFECT
M1	temp	TOD	wind	cloud	light	month	survey	Location.site
M2	temp		wind	cloud	light	month	survey	Location.site
M3		TOD	wind	cloud	light	month	survey	Location.site
M4	temp	TOD	wind	cloud	light		survey	Location.site
M5	temp		wind	cloud	light		survey	Location.site
M6		TOD	wind	cloud	light		survey	Location.site
M7	temp	TOD	wind	cloud	light			Location.site
M8	temp		wind	cloud	light			Location.site
M9		TOD	wind	cloud	light			Location.site
M10	temp	TOD	wind	cloud				Location.site
M11	temp		wind	cloud				Location.site
M12		TOD	wind	cloud				Location.site
M13	temp	TOD		cloud				Location.site
M14	temp			cloud				Location.site
M15		TOD		cloud				Location.site
M16	temp	TOD						Location.site
M17	temp							Location.site
M18		TOD						Location.site
M19				cloud				Location.site
M20			wind					Location.site
M21					light			Location.site
M22								Location.site

Detection likelihood relative to survey order:

Statistical Software and Packages

All statistical analyses and visualisations were conducted in R Version 2025.05.0+496 using a range of packages for modelling, data handling, and interpretation. The **lme4** package was used to build GLMMs with binomial and Poisson distributions. For model interpretation, the **parameters** package was used to extract and transform model outputs, including the conversion of log-odds to odds ratios, while **merDeriv** was used to calculate the standard errors for model estimates. The **MuMIn** package was useful for model selection and comparison based on AIC values. The **car** package was used to apply data transformations where needed, and **dplyr** and **tidyverse** provided tools for data manipulation and cleaning. Visualisations were generated using **ggplot2**, and model prediction plots were created using **sjPlot** to help display fitted relationships between predictors and vocal response outcomes.

Results

Crakes were detected at 14 of the 21 wetlands, with detections occurring at 33 of the 65 survey locations. At sites where crakes were confirmed, detection rates across repeated surveys varied between 0.72-0.94. (Figure 2-2). No responses were recorded on the sixth survey, but this is likely due to very few sites being surveyed that many times, rather than a true decline in detectability.

Across sites where spotless crake were detected, the cumulative first-detection curve shows that ~60% of sites yielded detections on the first survey, ~85% by the second survey, and 95% by the third survey. These results indicate that 2–3 surveys per site are generally sufficient to achieve high confidence of detecting crakes.

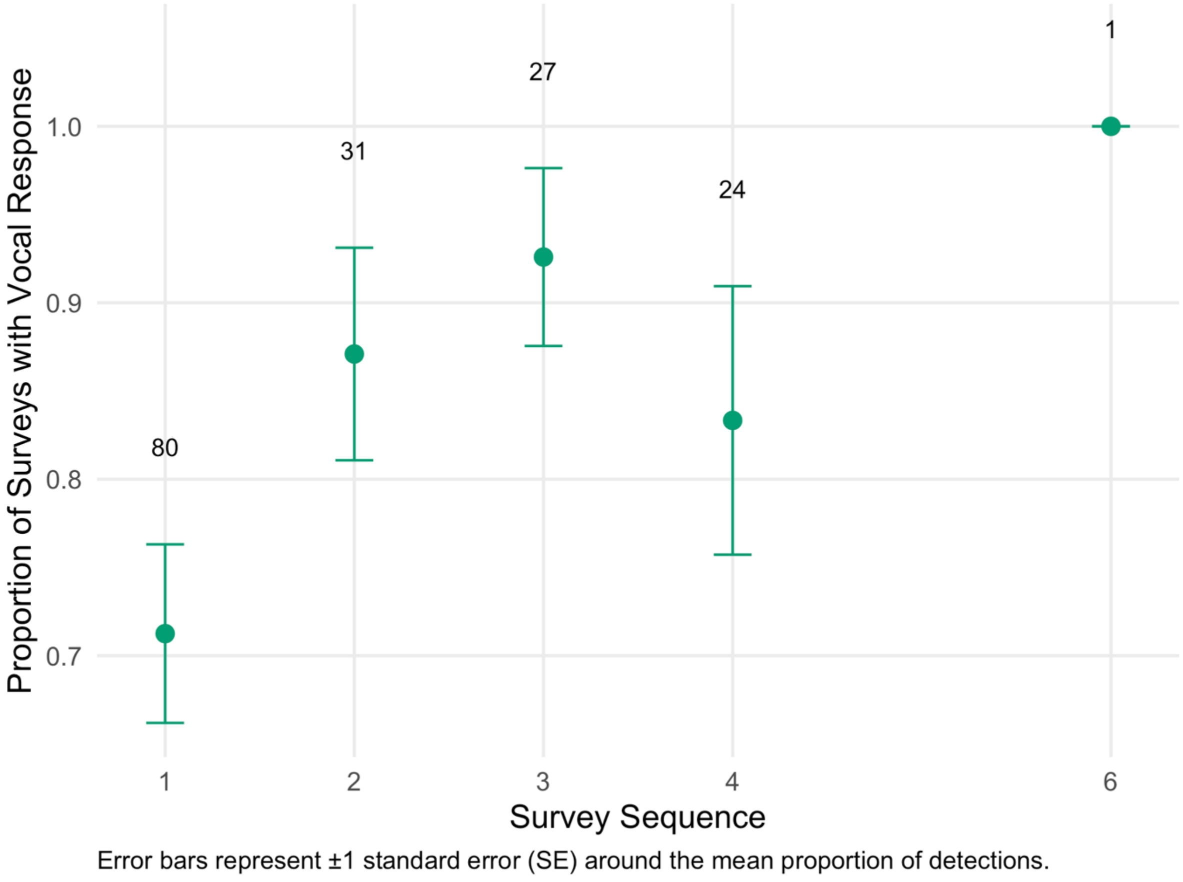
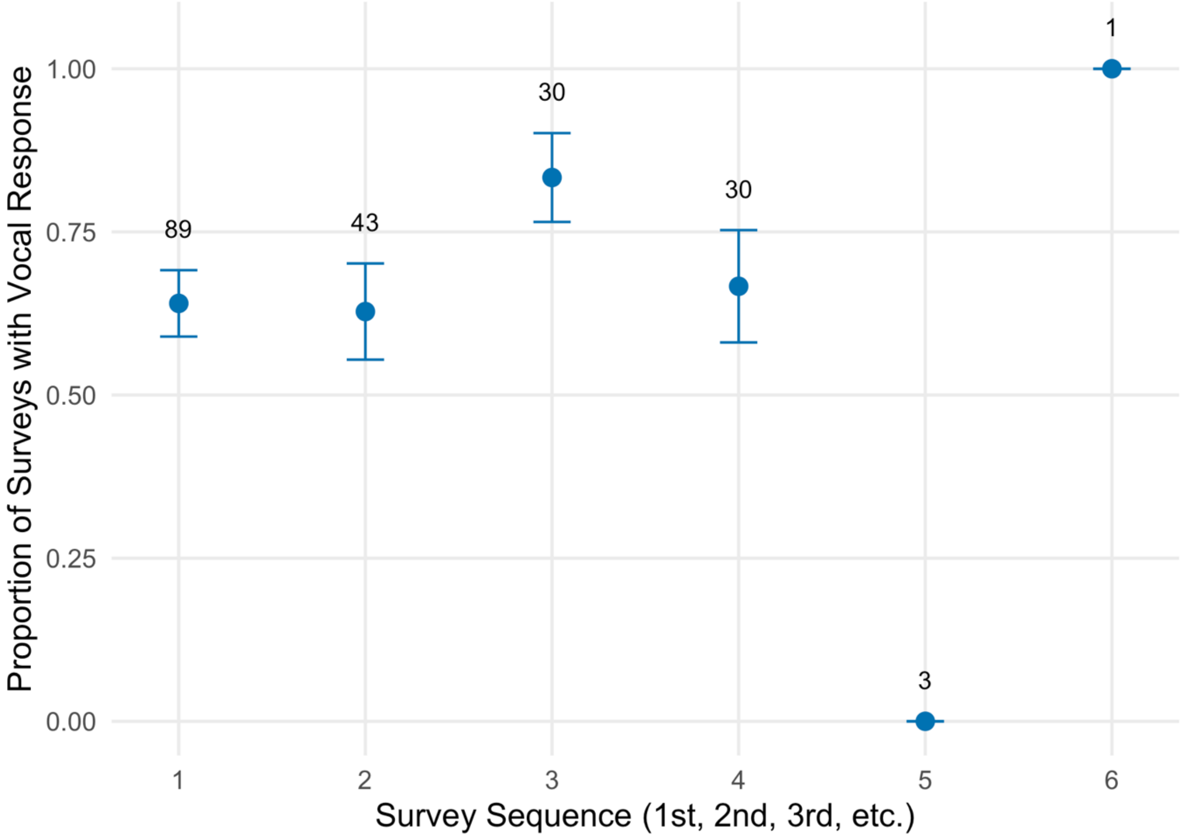


Figure 2-2. Detection probability across survey sequence for sites with confirmed crake presence. Sample sizes are given above each point.

The same plot was also created using data from all surveys regardless of whether crake presence had been confirmed (Figure 2-3). This broader analysis showed a very similar pattern to the one based on confirmed sites. The sixth survey showed no responses, which is almost certainly due to the small number of sites that were surveyed this many times. The consistency between the two plots suggests that detection patterns are not dramatically different between confirmed and unconfirmed sites, but the reliability of later survey sequences remains limited by sample size.



Error bars represent ±1 standard error (SE) around the mean proportion of detections.

Figure 2-3. Detection probability by survey sequence (confirmed sites).

Table 2-4. First detection of spotless crakes by survey.

Survey Sequence	Number of Sites	Notes
First survey	11 sites	e.g., Koitiata Swamp (Raupo corner), Lake Westmere (multiple points), Pukepuke Lagoon (First of 3 lakes), Karere Lagoon (Karere at swamp)
Second survey	6 sites	e.g., Koitiata Swamp (Centre swamp, Ridgeline), Lake Omanu (various points)
Third survey	4 sites	e.g., Koitiata Swamp (2nd swamp edge), Lake Alice (various points)
Fourth survey	0 sites	No first detections recorded at fourth survey
Later surveys	0 sites	No first detections recorded after fourth survey

Environmental influences on crake detection:

Binomial models of response versus no response

Three binomial models based on the full dataset had support based on their AIC values (Table 2-5, Appendix Figure 1). The top binomial model (m16) included temperature as the sole fixed effect, suggesting that it was the strongest individual predictor of crake detection. Time of day and/or temperature also appeared in the alternative models (m13 and m15), reinforcing the effect of time of day (given that time of day and temperature were related).

For model 15 the intercept indicated relatively high baseline odds of detecting spotless crakes (OR = 4.42, 95% CI: 0.37-52.74), although this effect was not statistically significant (p = 0.24; Table 2-6). Relative to the reference time period (06:00-08:00), detection odds were generally lower at all other times of day, but none of these contrasts reached significance. For example, odds were reduced in the 08:00-10:00 period (OR = 0.17, CI: 0.01-2.73, p = 0.21) and again in the 18:00-20:00 period (OR = 0.16, 95% CI: 0.01-3.62, p = 0.25), though confidence intervals were wide. Cloud cover showed a negative but non-significant effect on detection (OR = 0.86, 95% CI: 0.72-1.04, p = 0.12).

Table 2-5. Model selection results for binomial GLMMs of spotless crake vocal response (all sites).

K: Number of parameters in the model. AICc: Akaike Information Criterion. Delta_AICc: The difference in AICc from the best model. AICcWt: The probability that a given model is the best among the set. Cum.Wt: Cumulative Akaike Weight.

	K	**AICc**	**Delta_AICc**	**AICcWt**	**Cum.Wt**
m16	9	215.99	0.00	0.44	0.44
m13	10	216.63	0.64	0.32	0.76
m15	9	217.23	1.24	0.24	1.00

Table 2-6. Effect estimates from binomial GLMM predicting spotless crake detection probability (all sites).

Parameter	Odds Ratio	SE	95% CI	z	p
(Intercept)	4.42	5.59	[0.37, 52.74]	1.17	0.240
TimeOfDay [0800-1000]	0.17	0.24	[0.01, 2.73]	-1.26	0.209
TimeOfDay [1000-1200]	0.64	0.87	[0.04, 9.19]	-0.33	0.745
TimeOfDay [1200-1400]	0.43	0.57	[0.03, 5.96]	-0.63	0.527
TimeOfDay [1400-1600]	0.75	1.04	[0.05, 11.36]	-0.2	0.839
TimeOfDay [1600-1800]	0.75	1.11	[0.04 13.68]	-1.19	0.847
TimeOfDay [1800-2000]	0.16	0.26	[0.01 3.62]	-1.15	0.252
Cloud	0.86	0.08	[0.72, 1.04]	-1.57	0.116

Non-significant predictors

Across all best-fitting models (Figure 2-3), most environmental and temporal variables contributed meaningfully to explaining spotless crake vocal response, either in terms of detection probability or calling rate. However, light level consistently emerged as a non-significant predictor. Although it was retained in the Poisson models for both all sites and confirmed sites (m2 and m3), its effect was small and confidence intervals overlapped zero, suggesting minimal influence on crake responsiveness. These findings suggest that while most environmental variables have some predictive power for vocal activity, light level may not be a reliable indicator of spotless crake responsiveness under typically survey conditions.

The best-supported model for predicting spotless crake response included temperature and cloud cover as predictors (Figure 2-2. Detection probability across survey sequence for sites with confirmed crake presence. Sample sizes are given above each point. and Figure 2-3). This indicates that these two environmental variables were the most important among the candidate set. Models including additional variables (e.g., vegetation structure or wetland size) had higher ΔAICc values, suggesting weaker support.

Table 2-7. Model coefficients for supported binomial Generalised Linear Mixed Models of spotless crake vocal response (all sites).

Model	Variable	Estimate	SE	Lower CI	Upper CI	P-value
Response ~ Cloud	Intercept	0.928	0.257	0.424	1.431	0.000
Response ~ Cloud	Cloud	-0.174	0.003	-0.180	-0.168	0.000
Response ~ Temp + Cloud	(Intercept)	-0.726	1.913	-4.474	3.023	0.704
Response ~ Temp + Cloud	Temp	0.073	0.081	-0.086	0.232	0.368
Response ~ Temp + Cloud	Cloud	-0.152	0.086	-0.320	0.016	0.07

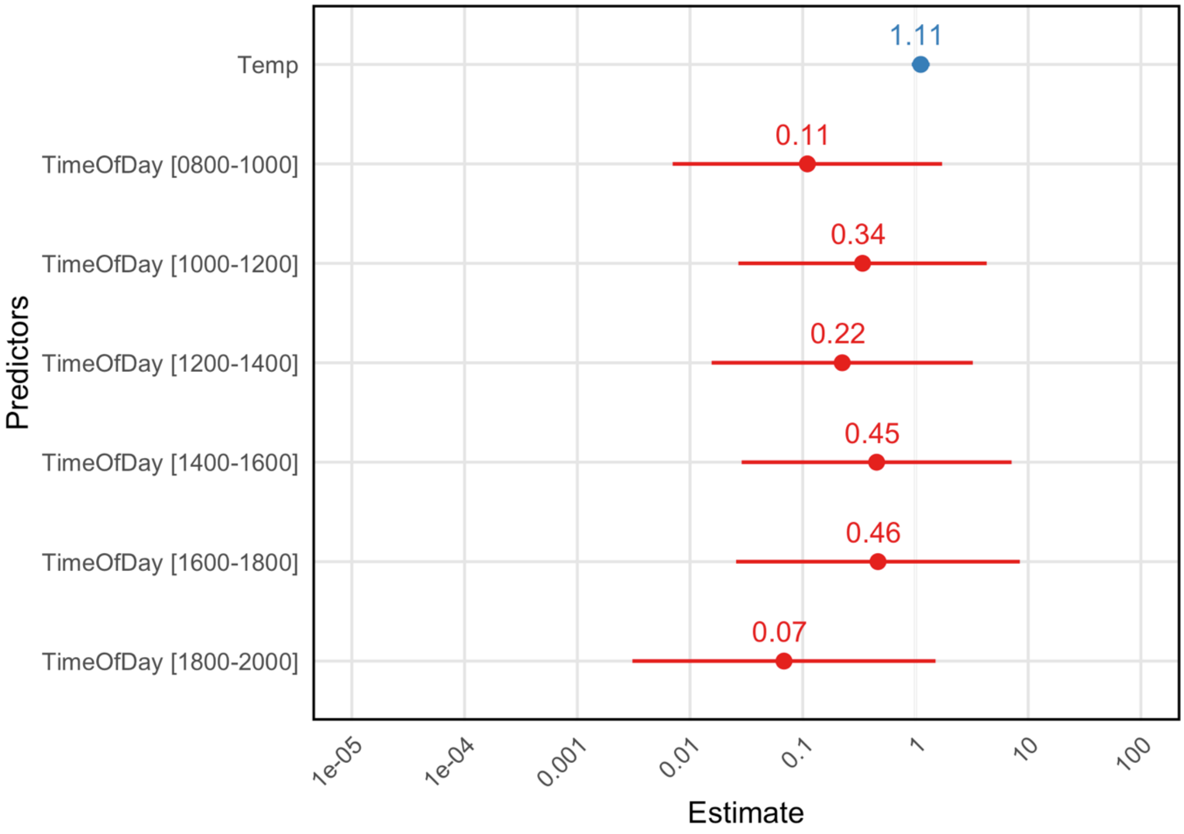


Figure 2-4. Effect sizes from model 16 (confirmed sites).

Site occupancy

Fourteen candidate occupancy models were evaluated. Model M14 was the only supported model (Table 2-8), receiving all model weight (AICcWt = 1.00), indicating overwhelming support relative to all alterative candidate models.

Table 2-8. Model selection results for crake site occupancy: top-ranked model (14).

	K	AICc	Delta_AICc	AICcWt	Cum.Wt
M14	3	6.258065	0	1	1

Poisson models of the number of calls detected

All survey sites

Three candidate Poisson GLMMs were evaluated to predict the number of vocal responses across all survey sites (m2c, m3c, and m1c). These models differed primarily in the inclusion of temperature and/or month as predictor variables. Model m2c received the strongest support, with the lowest AICc (367.59) and an Akaike weight of 0.967. The remaining models had considerably less support (m3c: ΔAICc = 7.37; m1c: ΔAICc = 9.44), indicating that m2c was clearly the best-supported model.

Parameter estimates from the top-ranked model suggested that responses were generally lower during later time periods relative to the reference period (0600-0800). Cloud cover had a weak negative effect on response rates, while temperature showed a small effect. Overall, confidence intervals for all predictors overlapped zero, indicating limited evidence for strong effects here.

Confirmed crake sites

For the Poisson models predicting the number of vocal responses at confirmed crake sites, two supported models were identified (**Error! Reference source not found.**). Model 13d had the lowest AICc (312.61) and was therefore ranked highest, while model m16d received similar support (ΔAICc = 0.11), indicating that both models described the data well. The small difference in AICc suggests little evidence favouring one model over the other.

Across the supported models, time of day was consistently associated with variation in vocal responses, with lower response rates observed during later survey periods compared with the reference period (0600-0800). Temperature showed a weak positive effect on response rates, while cloud cover had a weak negative effect. None of these predictors were statistically significant indicating uncertainty in the strength of these relationships. Cloud cover was associated with low response rates, whereas time of day and month sequence generally showed positive coefficient estimates. Confidence intervals overlapped zero for all predictors, indicating uncertainty (Figure 2-5).

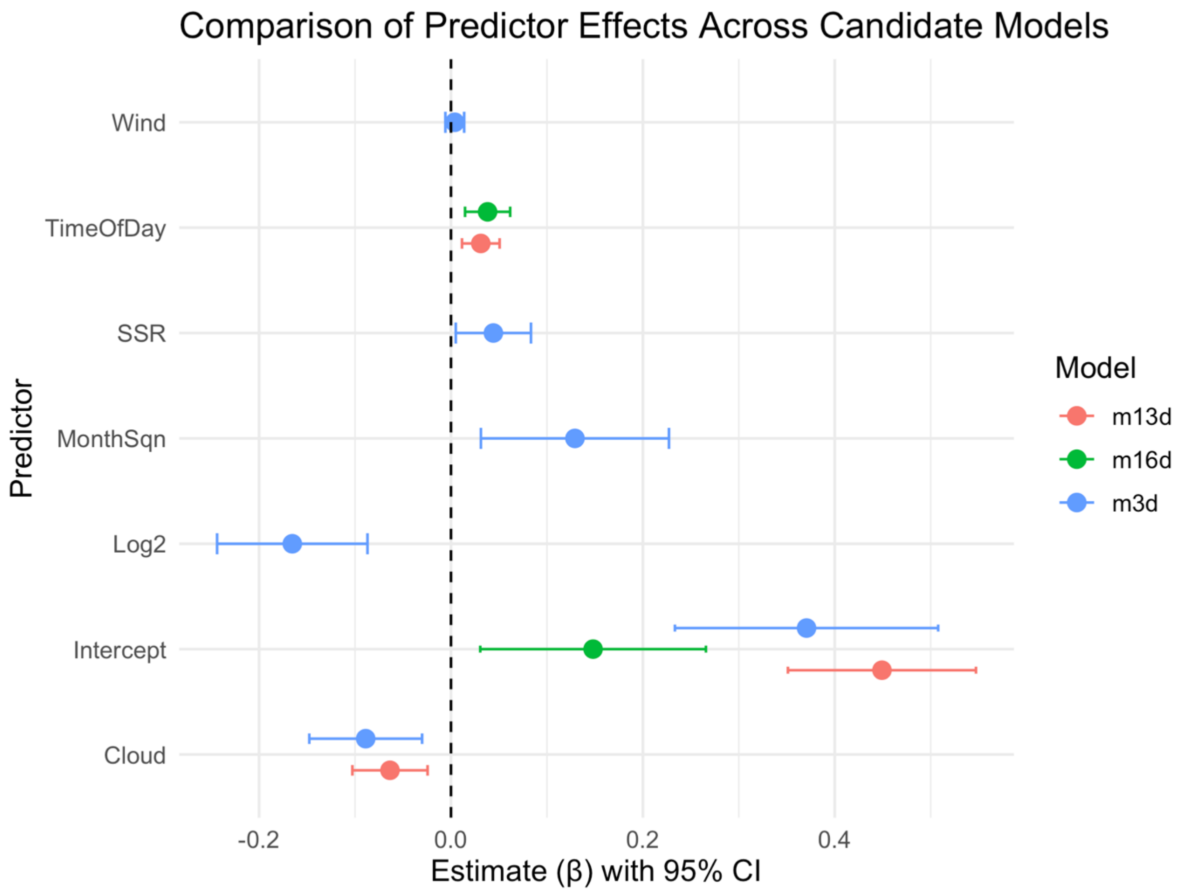


Figure 2-5. Comparison of predictor effects across candidate models

Table 2-9. Summary of significant predictors from Binomial and Poisson GLMMs of spotless crake vocal response.

Model Type	Site Type	Significant Predictors
Binomial Model	All Sites	Temperature, Time of Day
Binomial Model	Confirmed Sites	None
Poisson Model	All Sites	Temperature, Wind, Cloud, Light, Month
Poisson Model	Confirmed Sites	Time of Day, Wind, Cloud, Light, Month

Significant predictors across models:

For the binomial models predicting detection probability, temperature and time of day were significant predictors in the all-site models, while no predictors were significant at confirmed crake sites (Table 2-9). In contrast, the Poisson models predicting the count of vocal responses identified a broader range of significant environmental variables.

At all sites, temperature, wind, cloud cover, light conditions, and month influenced calling rates. At confirmed crake sites, time of day replaced temperature as a significant predictor alongside wind, cloud cover, light conditions, and month. These results suggest that environmental conditions may influence detection probability and calling intensity differently depending on both the response variable and the subset of sites analysed.

Time of day emerged as the most consistent predictor across modelling approaches, influencing either detection probability or vocal response rates in most supported models. Environmental variables such as cloud cover, wind, light conditions, and month appeared more important for explaining variation in calling intensity than for explaining simple detection/non-detection.

Discussion

Environmental influences on crake response rates:

The influence of environmental conditions on spotless crake detection was evident in the modelling results. Temperature consistently exhibited a significant positive relationship with both detection probability and response counts across all sites, highlighting the species' increased activity under warmer conditions. Time of day also emerged as an important predictor, particularly within confirmed sites, where it was sometimes a more important predictor than temperature in explaining variation in responsiveness. Wind speed and cloud cover were negatively associated with vocal response rates in several top Poisson models, especially in confirmed sites, suggesting that adverse weather can suppress or mask calling behaviour. In contrast, light intensity had minimal impact, with confidence intervals overlapping zero in most models. These findings indicate that environmental factors, particularly temperature, wind, and survey timing, substantially influence crake detectability. Incorporating these variables into survey design is therefore critical for optimising detection rates and accurately assessing habitat use.

The binomial models revealed different drivers of detection probability depending on the dataset considered. Across all surveyed sites, model 16 identified temperature and time of day as the strongest predictors of detecting a vocal response in spotless crake. The effect of time of day aligns with known patterns of peak vocal activity in early morning and late afternoon, while temperature likely reflects broader environmental conditions influencing bird activity or seasonality. In contrast, the analysis restricted to confirmed sites found that the null model (model 22) was the best-fitting model. This suggests that once presence is confirmed, crakes respond consistently regardless of minor variation in weather or survey timing. Alternatively, the lack of significant effects may reflect reduced sample size or greater influence of local factors, such as individual behaviour or fine-scale habitat characteristics, which were not measured. These results highlight the importance of considering environmental and temporal variables when surveying across a broad set of sites, while also noting that at occupied sites other local or individual-level factors may be more influential in determining detectability.

The Poisson models reveal that a combination of environmental and temporal factors influences the intensity of crake calling behaviour. Across all sites, model 2 identified temperature, wind, cloud cover, light levels, month, and survey sequence as important predictors, indicating that both weather conditions and survey timing affect not only whether crakes respond, but also the extent of their vocal activity. Increased wind and cloud cover likely suppress calling or reduce calling behaviour, while light levels and survey timing may interact with seasonal and daily activity patterns.

This may reflect the species' activity patterns being driven more by circadian rhythms than absolute light intensity, a trend observed in other cryptic, wetland birds (Conway 2009). In contrast, other predictors—such as temperature, time of day, wind, cloud cover, month, and survey sequence—were found to be significant or conditionally important in at least one modelling context, aligning with previous studies highlighting the influence of environmental and survey timing on wetland bird detectability (McKelvey 2001).

Within confirmed sites, model 3 retained most of the same predictors but substituted temperature with time of day, which suggested that daily activity rhythms may better explain variation in call counts where crakes are already known to occur. Despite this, temperature remained a key driver overall, with higher temperatures associated with increased likelihood and frequency of vocal responses. Time of day had a smaller effect, slightly increasing response probability during peak activity periods, but its influence was less than temperature. These findings highlight the importance of considering both environmental conditions and survey timing when assessing vocalisation patterns and designing effective monitoring protocols for cryptic wetland birds.

Environmental Drivers of Spotless Crake Vocal Behaviour

The influence of environmental factors on spotless crake vocal behaviour varied depending on the response variable and spatial scale considered. Across all survey sites, detection probability (binomial generalised linear mixed models) increased with higher temperatures and peaked during dawn and dusk. Detection was slightly reduced under strong wind or overcast conditions, and month was significant, with the highest detection in October-December ($p < 0.05$).

For calling activity (Poisson generalised linear mixed models), the number of calls per survey was positively associated with warmer temperatures and higher light levels but decreased under strong wind or heavy cloud cover. At confirmed sites, time of day became particularly important, with calling peaking at dawn and dusk. Month also influenced activity, with the highest calling rates observed in November-December. Survey sequence did not have a consistent effect, indicating that repeated playback did not lead to habituation.

The differing results between the binomial and Poisson models highlight important nuances: factors driving whether crakes respond at all (presence/absence) can differ from those influencing the intensity of vocal activity once present. Across all sites, temperature, wind, cloud cover, light, and month played key roles, whereas at confirmed sites, time of day emerged as a more influential driver alongside the other variables. These patterns suggest behavioural adjustments of crakes to local conditions and/or differences in dataset composition. Examining multiple response variables across spatial scales provides a more comprehensive understanding of the environmental drivers of vocal behaviour in cryptic species like the spotless crake. This insight is essential for refining survey protocols and improving detection accuracy.

Likelihood of Response Relative to Survey Order

The sequence of surveys at each site indicated that first detections of spotless crakes most often occurred within the two first visits, with occasional detections on later visits. Detection probability remained broadly consistent across repeated surveys, suggesting that birds do not learn playback. Sites where crakes were not detected until later surveys highlight the importance of conducting multiple site visits (typically 2–5) to achieve high confidence of presence, especially for cryptic species with variable calling behaviour. These findings reinforce previous recommendations for repeated call-based surveys to account for imperfect detection (McKelvey and Pearson 2001).

Statistical Analysis of Vocal Response Probability

Poisson GLMMs were utilised to model the count of calls recorded per survey period, enabling the investigation of variation in calling rate conditional on detection. These models help identify environmental and temporal factors that influence the intensity of vocal activity, which can reflect behavioural traits like territoriality, mate attraction, or responses to environmental conditions.

Complementarity of Binomial and Poisson Models

The combined use of binomial and Poisson GLMMs allows us to disentangle two key components of vocal detection: (i) whether a spotless crake responds vocally during a survey, and (ii) the frequency of calls produced given that a response occurs. This distinction is especially valuable in ecological monitoring, where imperfect detection can obscure ecological signals. Patterns that are consistent across both models e.g., higher probability of response and elevated call counts under certain vegetation conditions provide robust evidence of biologically meaningful relationships. Conversely, differences between models may reveal behavioural nuances, such as variable calling rates despite stable detection probabilities, offering deeper insight into species ecology. The analysis was further refined to include only surveys at confirmed crake presence sites, allowing assessment of detectability variation independent of occupancy.

Results showed that for the full dataset (all sites), model m16, including temperature and time of day, best explaining detection probability (binomial response), while model m2, including temperature, wind, cloud, light and month, best explained calling rate (Poisson response). In contrast, when the dataset was restricted to confirmed sites, model m22 (intercept-only) was the best fit for detection probability, suggesting no strong environmental predictors influenced vocal response presence in this subset. For calling rate at confirmed sites, model m3 (time of day, wind, cloud, light and month) was best supported.

This difference between datasets highlights how including sites with uncertain occupancy can influence model outcomes and ecological inference. Notably, time of day emerged consistently as a key predictor of vocal behaviour, particularly at confirmed sites, underscoring its importance in designing effective survey protocols. Meanwhile, other environmental variables such as temperature, wind, and cloud cover appear to influence call frequency, likely reflecting behavioural responses to fluctuating environmental conditions.

Model selection and interpretation:

The identification of temperature and time of day as key predictors in the binomial model for all sites (model 16) suggests that spotless crakes are more likely to respond vocally during surveys conducted under warmer conditions and earlier in the day. These findings are consistent with known behavioural rhythms in other cryptic wetland birds, where vocal activity is often concentrated during cooler morning hours (Pérez Granados 2018). Temperature likely affects calling behaviour both directly, through physiological constraints, and indirectly via effects on prey availability or habitat use. Additionally, calling at dawn and dusk may function in territory maintenance or mate attraction, analogous to the dawn chorus observed in passerines, suggesting a behavioural as well as environmental component to temporal patterns in vocal activity.

The Poisson models revealed a more complex set of predictors influencing call rate, including wind, cloud cover, light, and month. Increased wind and heavy cloud cover were generally associated with reduced vocal activity, likely due to their negative effects on sound transmission and ambient noise levels (Tozer 2007). Lower light levels may also suppress calling, particularly for species that rely on visual cues alongside acoustic communication. Seasonal patterns likely reflect reproductive timing, as crakes are expected to vocalise more during peak breeding activity.

Interestingly, the absence of significant predictors in the best-fitting binomial model for confirmed sites (model 22) may reflect a ceiling effect – once habitat is known to support crakes, detection becomes less dependent on environmental variability and more influenced by intrinsic factors such as individual condition or territorial dynamics. Alternatively, this result could suggest that variation in detectability at these sites is better explained by unmeasured microhabitat or social factors, rather than broad-scale environmental conditions.

From a management perspective, these results highlight the importance of carefully selecting survey conditions to maximise detection probability. Surveys conducted early in the day, particularly during warmer, calm, and well-lit conditions, are more likely to yield responses. This is especially crucial for rare and cryptic species like the spotless crake, where limited detections can lead to underestimation of population size or distribution.

Furthermore, the findings emphasise the value of repeat surveys. The detection probability plot by survey sequence showed that responses were relatively consistent across the first five visits, but dropped off by the sixth – likely due to the small number of surveys extending to that point. Repeat visits (up to 3-5) are justified to confirm presence, particularly in habitats where occupancy is uncertain or detection is known to be variable.

In practice, conservation agencies such as the Department of Conservation or regional councils could use these insights to optimise wetland monitoring protocols. By aligning survey timing with environmental conditions that favour vocal responses, and by prioritising multiple visits per site, managers can improve the reliability of detection data and better inform habitat protection and species management strategies.

Integrating Environmental Predictors to Improve Crake Monitoring

The modelling results highlight how environmental variables can strongly influence spotless crake vocalisation patterns, with time of day and temperature emerging as consistent predictors across both the full and confirmed-site datasets. However, differences between these two model sets reveal the potential impacts of detection bias. When all sites were included, temperature significantly influenced vocal response rate, potentially reflecting undetected crakes at colder sites where vocal activity was suppressed. In contrast, at sites with confirmed crake presence, time of day alone explained most of the variation suggesting more reliable calling behaviour under known occupancy. This difference underscores the importance of accounting for imperfect detection in survey design and analysis. The additional Poisson models supported these findings and offered a more overarching understanding of response counts revealing that multiple environmental factors may play a role in influencing detectability. Collectively, these results suggest that monitoring programs for cryptic wetland species like the spotless crake would benefit from a comprehensive approach that incorporates site-level variability, optimal survey timing, and environmental conditions to improve detection reliability and habitat inference.

Bias and Accuracy in Crake Detection Implications for Monitoring Methods

If we restricted the analysis to sites where we confirmed the presence of spotless crakes it is likely that the results would vary. Limiting the scope in this way could exclude sites where crakes are present but not detected, potentially leading to an overestimate of detection success or an underrepresentation of the factors influencing species presence (Farmer 2012). This could impact the generalisability of findings and reduce the accuracy of conclusions drawn about the species' habitat use and the effectiveness of monitoring methods.

Understanding the Limitations of Presence-Only Data in Ecological Surveys

For cryptic and elusive species like the spotless crake, detection bias may lead to an underestimation of their distribution as some sites where crakes are present but undetected may be overlooked. Factors such as low vocalisation rates, dense vegetation, or adverse weather conditions could prevent detection, yet these issues are not accounted for in presence-only data (Phillips 2009).

Furthermore, relying solely on presence-only data may not accurately reflect the full range of habitat types utilized by the spotless crake. Restricting surveys to areas where the species has already been detected risks overlooking wetlands that could support crakes but where they were not previously recorded. This approach may therefore fail to identify important habitats for conservation and management, leading to an unfinished picture of the species' ecological requirements. Survey efforts often focus on habitat types where crakes are known or suspected to occur, rather than only revisiting exact known locations, but even this strategy may not fully eliminate the risk of missing cryptic or seasonally transient populations.

Presence-only data also fail to capture the absence of the species in relation to environmental factors such as temperature, vegetation structure, or water levels which may influence the crake's distribution. The absence of the species at a site does not necessarily indicate an unsuitable habitat; it could simply reflect a missed detection due to time of day, seasonality or weather conditions. Without understanding why a site has no detections, it becomes difficult to make informed decisions about the crake's habitat preferences or the effectiveness of monitoring techniques.

Moreover presence-only data can lead to the over/underestimation of the crake's abundance or population density. The assumption that presence at a site indicates consistent or high levels of activity may result in inaccurate conclusions about the species population. For cryptic species like the spotless crake which may not vocalise or be active under certain conditions, presence-only data is unlikely to reflect the true abundance or distribution patterns of the species.

Another significant limitation is that presence-only data often overlooks temporal variation in species activity (Aubry 2017). The spotless crake exhibits seasonal and time-of-day shifts in its vocalisation and activity which may not be captured if surveys are only conducted at previously known sites. Without considering factors such as breeding seasons or the time of day, presence-only data may miss critical aspects of the species behaviour and movement patterns leading to a skewed understanding of its ecological needs.

Challenges in Estimating Spotless Crake Presence: The Role of Undetected Populations

Estimating the presence of the spotless crake presents a significant challenge due to its cryptic nature and elusive behaviour. This small secretive wetland bird is difficult to detect even when it occupies a site, making accurate estimations of its distribution and abundance complex. A major challenge in estimating crake presence is the potential for undetected populations which can lead to significant underrepresentation of the species true distribution.

For cryptic species like the spotless crake, detection is heavily influenced by a variety of environmental and ecological factors. Dense vegetation, low vocalisation rates, and adverse weather conditions such as high winds or heavy rain can all limit detection even in areas where crakes are present. This creates a risk that some habitats may be overlooked in surveys leading to inaccurate conclusions about the species distribution.

Additionally, temporal and seasonal shifts in the crakes' behaviour complicate detection efforts. The species' activity levels may vary depending on the time of day, season, or breeding status, which means that surveys conducted outside of peak activity periods may fail to detect crakes even in areas where they are present. Without accounting for these fluctuations, monitoring efforts may not accurately capture the species' full range of activity leading to skewed estimates of population size and distribution.

Overall, the challenge of estimating spotless crake presence is shaped by the combination of the species' cryptic behaviour, environmental factors influencing detectability and temporal fluctuations in its activity. To improve the accuracy of detection, it is essential to consider these variables and incorporate more comprehensive survey methods, including broader sampling periods, a wider range of environmental conditions and innovative monitoring techniques. Only by accounting for undetected populations and the factors influencing detectability can we gain a more accurate understanding of the spotless crake's distribution abundance and ecological requirements.

The Implications of Restricted Survey Sites on Species Detection and Habitat Use

Limiting surveys to sites where species presence has already been confirmed can significantly impact the accuracy and generalisability of ecological findings—particularly for cryptic species like the spotless crake. While this approach may increase the likelihood of detections, it risks introducing detection bias and overlooking important aspects of the species habitat use and distribution.

For the spotless crake, which is difficult to observe and detect, restricting surveys to known locations could lead to a skewed understanding of the species ecology. Sites where the species is present but undetected— due to factors like low vocal activity, dense vegetation, or unfavourable weather conditions— may be incorrectly assumed to be unoccupied. This can result in an overestimation of detection success and a limited picture of the full range of habitats the species uses.

Such a narrow survey approach may also exclude marginal or transitional habitats that are important for the crake's movement, foraging or breeding. By focusing only on previously confirmed locations, researchers risk missing out on critical information about habitat variability and suitability across a landscape. This in turn can affect conservation planning as areas essential for maintaining population connectivity or resilience may not be identified or prioritised. Furthermore, conclusions drawn from a restricted sample of sites may not be applicable to other regions or wetland systems, reducing the broader utility of the research. For effective species management and conservation, it is essential to understand not only where a species is currently found but also where it could be found under different conditions or following restoration efforts.

To address these limitations, future surveys should incorporate a more representative range of sites including both known and potential habitats. This approach combined with robust survey methodologies that account for detection probability will provide a more accurate and comprehensive understanding of the spotless crake’s habitat use and support more effective conservation outcomes.

Chapter 3 - Silent Signals, Crake Habitat Clues

Abstract

Wetland loss and fragmentation pose significant threats to cryptic wetland birds such as the spotless crake (*Porzana tabuensis*). This study investigated habitat associations of spotless crake across wetlands in the Manawatū-Whanganui region of New Zealand using systematic surveys, logistic regression, and random forest analysis. Reedland was identified by the logistic regression as positively correlated with crake presence, while wetland area and total area were also highlighted by the random forest analysis as positive predictors. In contrast, proximity to other wetlands within 1 km and 5 km had limited influence, suggesting that local-scale habitat features are more critical than broader landscape context. These findings indicate that dense, emergent vegetation and larger wetland areas support crake presence, highlighting habitat features that can inform monitoring strategies and wetland restoration efforts for cryptic rallids across Australasia.

Introduction:

The spotless crake (*Porzana tabuensis*) is a small secretive rail inhabiting wetlands throughout Aotearoa New Zealand and parts of Australasia and the Pacific. As a cryptic and largely nocturnal species, its ecology remains poorly understood with limited information available on its habitat preferences and distribution. Wetland degradation and modification have contributed to declines in suitable habitat for many wetland birds, including rails, yet the elusive behaviour of species like the spotless crake makes it difficult to assess their population trends and habitat requirements with confidence.

Habitat quality plays a pivotal role in the persistence of wetland-dependent bird species, particularly those that are highly specialised or have limited dispersal ability. For cryptic taxa such as the spotless crake, fine-scale habitat features such as vegetation, density, water levels, and edge complexity may influence detectability occupancy and reproductive success. However, the degree to which spotless crakes rely on specific vegetation structures or wetland types remains unclear, particularly across regional landscapes where wetland composition and condition vary considerably. This chapter investigates habitat quality for spotless crake in the Manawatū-Whanganui region with an emphasis on vegetation structure and wetland characteristics associated with their presence. Given the challenges of detecting this species, the study incorporates both direct detections and environmental variables to assess patterns in habitat use.

The analysis focused on the structural characteristics of vegetation including the density and extent of fringing vegetation, as well as broader environmental features such as water depth, wetland type, and surrounding land use. Understanding how landscape context influences species presence is critical for effective conservation planning. For the spotless crake, the abundance and proximity of nearby wetlands may affect habitat suitability by providing additional resources or facilitating movement between sites. I also investigate the relationship between crake presence and the density of surrounding wetlands within 1 km and 5 km radii to assess the potential importance of landscape-scale connectivity for this cryptic species. Data were collected using a combination of acoustic monitoring and field-based habitat assessments, allowing for the identification of fine-scale habitat preferences. Generalised linear mixed models GLMMs were employed to explore the influence of key habitat variables while accounting for variation between sites. By identifying key habitat features and assessing habitat flexibility, this study supports more targeted conservation actions and improved survey protocols for rare and understudied wetland fauna.

Methods

Introduction to Methods and Study Sites

I surveyed 22 wetland sites in the Manawatū-Whanganui region to assess spotless crake presence (see Chapter 2) in relation to local and landscape-scale habitat features. Site characteristics (Table 0-2) included wetland area, perimeter, shape, and connectivity. Vegetation types were classified via GIS and field observations into six categories. To quantify the physical characteristics and spatial context of each wetland (Table 0-2), measurements were conducted in QGIS (v3.34).

Wetland habitat area (in hectares) and perimeter length (m) were calculated using digitised wetland boundaries, either traced manually from high-resolution aerial imagery or sourced from existing spatial layers provided by Horizons Regional Council. These polygons were used to generate area and perimeter statistics via the “Field Calculator” tool. To assess wetland connectivity, spatial buffers with radii of 1 km and 5 km were generated around each wetland using the “Buffer” tool. The number of discrete wetlands within each buffer zone was then counted by overlaying the buffer layers with the regional wetland shapefile and using the “Select by Location” function. This allowed for assessment of landscape-scale wetland density and isolation, which may influence habitat suitability and species presence.

Table 3-1. Names and locations of study locations. Locations are ordered alphabetically.

Unique Locations	Latitude (ºS)	Longitude (ºE)
Ashhurst Domain Wetland	40.29992062	175.7580036
Broadlands Wetland	40.244340	175.781522
Fault Fen Wetland	40.360435	175.802453
Ferry Reserve	40.46408204	175.2545275
Kaikai & Operau Wetland	40.54358852	175.2273267
Karere Lagoon	40.40228912	175.5258025
Karere Road	40.4060272	175.5371638
Koitiaka Swamp	40.06957433	175.1354329
Kuku Beach Rd	40.66408006	175.1646685
Lake Alice	40.13441912	175.3319183
Lake Graeme	40.57109364	175.225226
Lake Omanu	40.45026512	175.2513373
Lake Papaitonga	40.64401491	175.2250886
Lake Westmere	39.89472893	174.9989246
Lake Wiritoa	39.97452476	175.0898539
Pohangina Luterells Garden	40.17475863	175.7912066
Pohangina Wetlands Dev	40.17599647	175.7932022
Pukepuke Lagoon	40.34170821	175.2656641
Raumai Lagoon	40.21464706	175.7763922
Waayer's Wetland	40.2091882	176.2129537
Waikawa Beach	40.69701559	175.1429987
Woodville Ferry Reserve	40.33588828	175.8169156

Table 3-2. Wetland morphology and proximity to nearby wetlands.

Wetland	Total Area (ha)	Wetland Vegetation Area (ha)	Perimeter (m)	Wetland shape	Wetlands within 1 km	Wetlands within 5 km
Ashhurst Domain Wetland	16.598	10	1318	Oxbow	0	0
Broadlands Wetland	15.637	9.662	2018	Long and wide	0	0
Fault Fen	3.553	2.075	737	Oval	0	2
Kaikai & Operau Wetland	24.383	23.018	3259	Oval	5	11
Karere Lagoon	17.081	11.959	2771	Oxbow	1	2
Karere Road	8.316	6.692	2284	Oxbow	1	2
Koitiaka Swamp	9.6	9.6	526	Long and narrow	1	6
Kuku Beach Road Wetland	0.703	0.448	1819	Long and narrow	1	11
Lake Alice	65.68	34.635	6058	Long and narrow	1	6
Lake Graeme	5.4	5.3	2437	Long and narrow	6	17
Lake Omanu	30.175	18.492	3061	Long and wide	0	5
Lake Papaitonga	132.212	88.31	5197	Oval	0	12
Lake Westmere	20.154	13.3	2055	Long and wide	0	4
Lake Wiritoa	74.091	50.627	6460	Long and narrow	0	4
Pohangina Wetlands Development	7.5	7.5	1250	Long and narrow	1	3
Pukepuke Lagoon	68.912	52.8	3958	Long and wide	0	3
Raumai Lagoon	3.76	3.6	980	Oval	0	2
Waayers Wetland	1.37	1.37	597	Long and narrow	1	1
Waikawa Beach Wetland	16	12	693	Oval	0	4
Woodville Ferry Reserve	2.709	1.949	660	Oval	0	2

Vegetation Classification

Major vegetation types at the study sites were identified from GIS layers and field observations. Six main vegetation types were recorded at the sites (definitions follow the New Zealand Classification of Vegetation Cover).

Reedland: Wetland vegetation dominated by tall reed-like species such as *Phragmites* or *Typha*

- Present at: Pukepuke Lagoon, Raumai Lagoon, Lake Omanu, Lake Wiritoa, Waikawa Beach

Grassland: Areas dominated by low herbaceous grass species, often with limited shrub or tree cover

- Present at: Raumai Lagoon, Waayers Wetland, Karere Road, Kuku Beach Road Wetland

Mānuka-kānuka Scrub: Shrubland dominated by manuka (*Leptospermum scoparium*) and/or kanuka (*Kunzea ericoides*).

- Present at: Koitiaka Swamp, Waayers Wetland

Indigenous Forest: Areas of closed-canopy native forest, typically featuring species such as tawa, rimu, and kahikatea

- Present at: Lake Papaitonga, Pohangina Wetlands Development

Exotic Treeland/Woodland: Areas where exotic trees, often willows or poplars, form a sparse or dense canopy

- Present at: Karere Lagoon, Raumai Lagoon, Lake Graeme, Ashhurst Domain Wetland

Coprosma-Olearia Scrub: Mixed native shrubland typically composed of divaricating *Coprosma* spp. and *Olearia* spp.

- Present at: Pukepuke Lagoon, Raumai Lagoon

Spatial Analysis

To assess how wetland shape influences the probability of spotless crake presence, a logistic regression model was fitted with crake presence/absence as the binary response variable and wetland shape as a categorical predictor. Predicted probabilities of crake presence for each wetland shape category was extracted from the model along with their 95% confidence intervals. These predictions were then visualised using a bar plot with error bars to display uncertainty. Wetlands were given a shape category based on visual assessment of their spatial outlines using GIS layers. Each wetland was assigned to one of four shape categories: “Oxbow, Oval, Long and Wide, and Long and Narrow”. This classification captures enough potential detail about the wetlands in terms of habitat structure and suitability for cryptic wetland species.

Statistical Analysis

First, vegetation types and the range of habitat conditions were summarised for sites where spotless crakes were confirmed to be present. To assess whether habitat characteristics differed between sites with and without confirmed crakes, non-parametric permutation tests were conducted on total wetland area (ha), perimeter (m), and perimeter-to-area ratio. Specifically, K-sample Fisher-Pitman permutation tests from the **coin** package were used. This approach does not rely on assumptions of normality and is therefore suitable for small sample sizes and unequal group variances. Further, an approximate K-sample

Fisher-Pitman permutation test was applied to compare wetland area across different wetland shape categories (long and narrow, long and wide, oval, and oxbow).

To further evaluate the predictive power of habitat features for crake presence, two complementary approaches were employed: logistic regression and Random Forest modelling. These methods allowed for examination of both linear and non-linear associations, providing insight into which habitat factors were most strongly associated with crake occurrence.

Logistic regression:

This logistic regression model assessed how local wetland context and vegetation types influenced the probability of spotless crake presence.

Random Forest Model Highlights Spatial Predictors

The Random Forest algorithm, developed by Breiman (2001), is a powerful classification and regression technique that builds multiple randomised decision trees and combines their predictions by averaging. It is useful in situations where the number of predictor variables exceeds the number of observations, and it is adaptable to various ecological data types. Prior to modelling, categorical variables were converted to factors, and continuous variables were standardised where appropriate. Variables with high multicollinearity were excluded. Missing values were handled by removing incomplete rows to ensure consistency across variables included in the model. The Random Forest model was fitted using randomForest() function, with 500 trees and the number of variables tried at each split set to the default. Variable importance was assessed based on the mean decrease in Gini index which indicates the contribution of each variable to classification performance. These findings contrast with the logistic regression model, which did not indicate any significant association with crake presence.

Results

Overview of Crake Detections

Spotless crakes were detected at 14 of the 22 surveyed locations (Figure 3.1). A comparison of vegetation types across surveyed wetlands showed patterns that indicate some habitat preferences from sites where spotless crakes were confirmed. Reedland was the most frequent vegetation type overall and was present at 12 of the 14 confirmed crake sites. Exotic treeland/woodland was present at 9 of the 14 crake sites and indigenous forest at 6 of the 14 sites. Grassland, Manuka-Kanuka scrub and *Coprosma-Olearia* were present at only 2–4 crake sites.

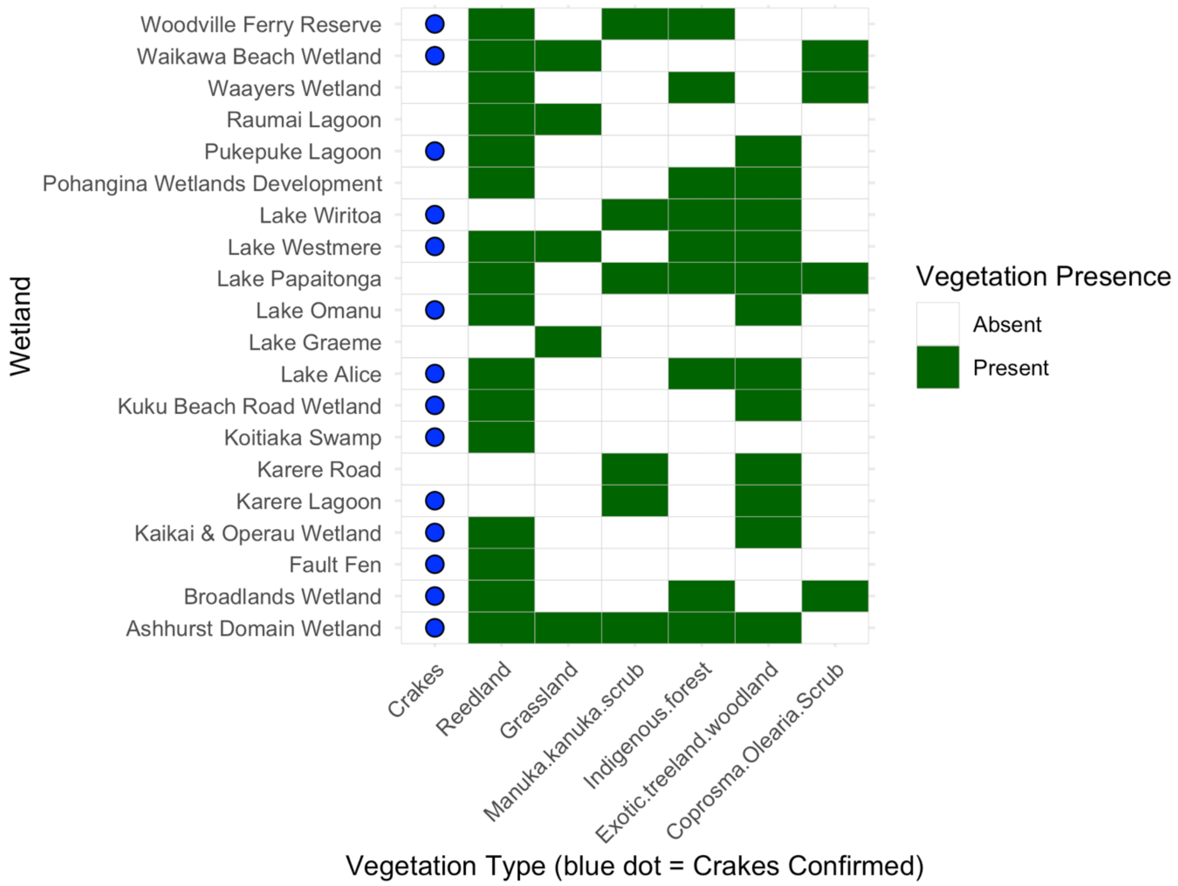


Figure 3-1. Spotless crake habitat: Vegetation presence and confirmed records.

Wetlands where crakes were detected ranged from approximately 1–51 ha in area, with perimeters 400–6500 m (Figure 3-2). Crake presence occurred across a variety of wetland shapes. Wetlands where crakes were absent were generally larger in area and perimeter, though some small wetlands also lacked crakes.

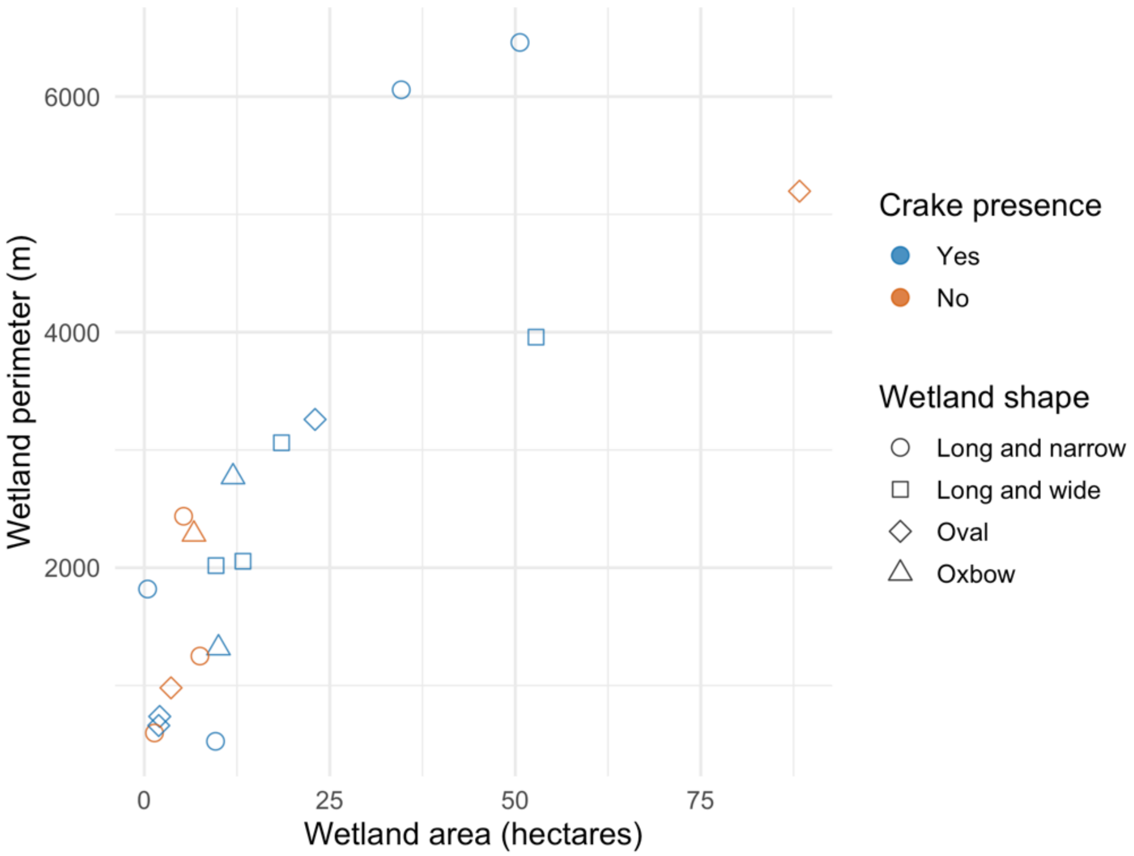


Figure 3-2. Area, perimeter and shape of sites surveyed for spotless crakes.

Figures 3-3 and 3-4 indicate that crake detections are more frequent at wetlands with lower connectivity, with sites having fewer neighbouring wetlands within 1 km and 5 km showing higher occurrence rates. This suggests that isolated wetlands may provide conditions more favourable for crake presence or detection.

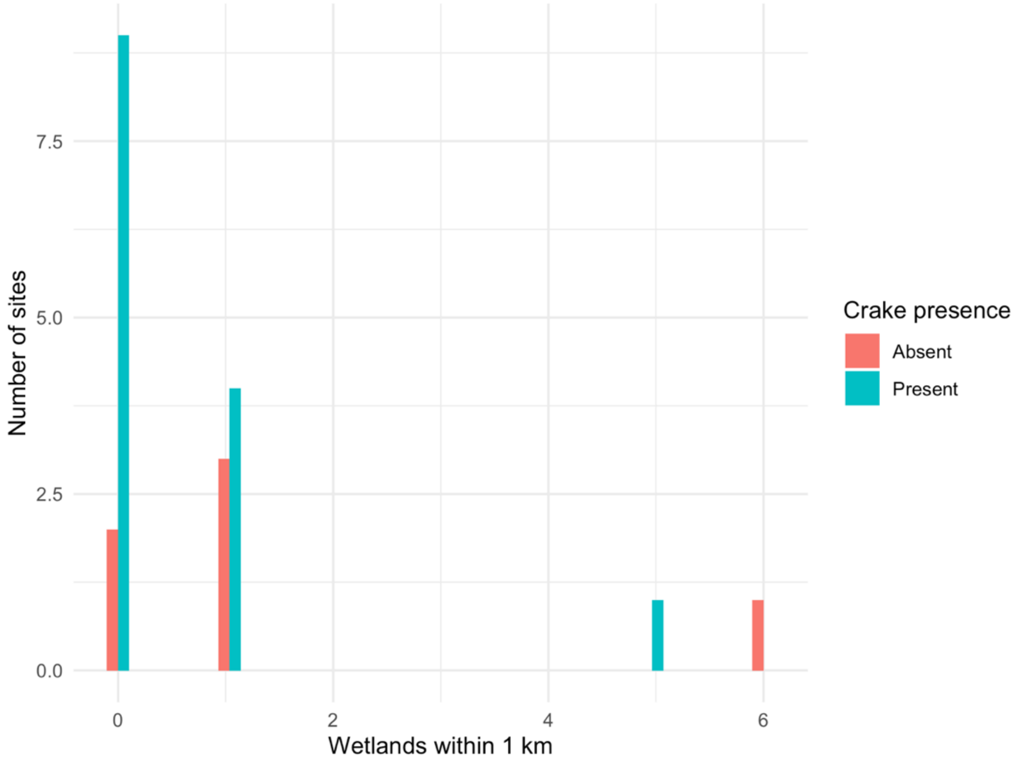


Figure 3-3. Number of wetlands within 1 km of survey sites, by spotless crake presence.

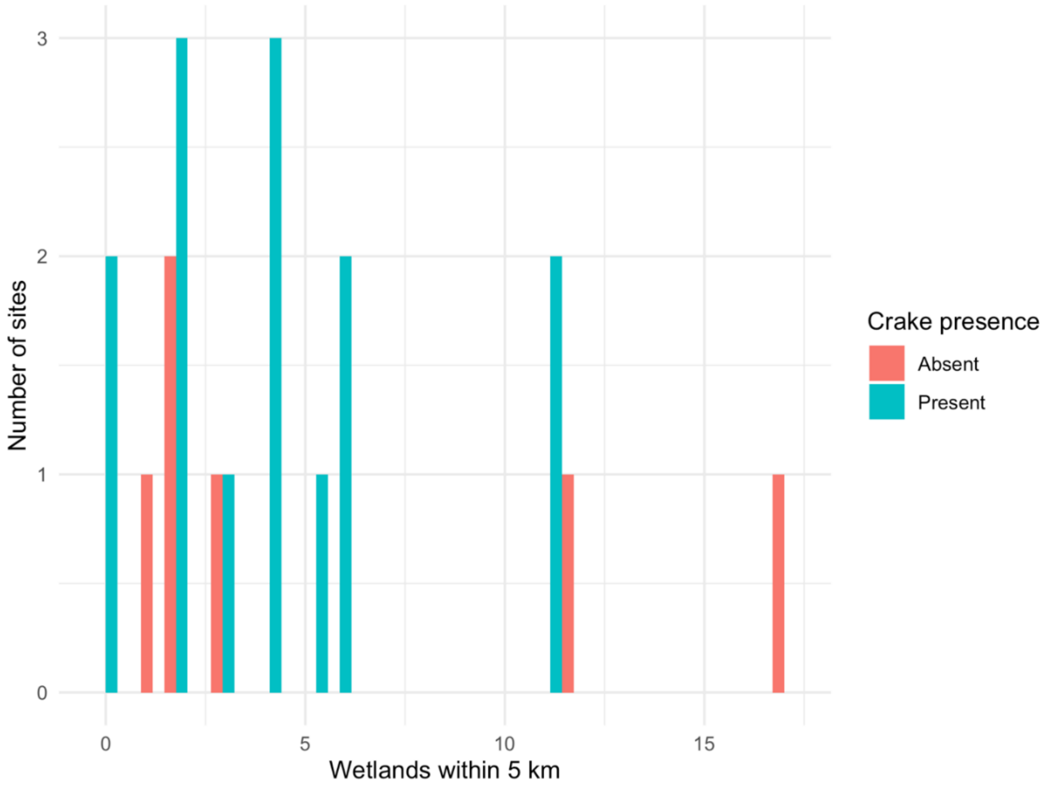


Figure 3-4. Number of wetlands within 5 km of survey sites, by spotless crake presence.

The logistic regression (Table 3-3) examined the influence of habitat variables and wetland metrics on crake presence. Reedland showed the largest effect, with an estimated odds ratio of 68, suggesting crakes were more likely to occur in reedland, although this result was not statistically significant (p = 0.143) and had a very wide confidence interval (0.797–123,901), reflecting uncertainty due to small sample size. Other habitat variables, including wetlands within 1 km and 5 km, grassland, total area, wetland area, and perimeter showed smaller effects with odds ratios close to 1 and were not statistically significant, indicating no strong evidence for these variables influencing crake presence in this dataset. Odds ratios for all habitat and landscape predictors were estimated, but none were statistically significant.

Table 3-3. Logistic regression results for crake presence and habitat characteristics.

Term	Odds Ratio	Std. Error	z value	P-value	Lower 95% CI	Upper 95% CI
(Intercept)	0.00656	3.70	-1.36	0.174	0.000000358	2.05
Wetlands within 1 km radius	0.301	1.27	-0.947	0.344	0.0140	2.95
Wetlands within 1 km radius	1.23	0.432	0.488	0.625	0.605	3.44
Reedland	68.0	2.88	1.47	0.143	0.797	123901
Grassland	0.288	1.78	-0.701	0.483	0.00402	9.08
Total Area	0.879	0.278	-0.466	0.641	0.430	1.47
Wetland Area	0.984	0.430	-0.0375	0.970	0.407	2.71
Perimeter	1.00	0.00193	1.55	0.122	1.00	1.01

Wetland Shape and Connectivity in Predicting Spotless Crake Presence

Wetland morphology, including shape and perimeter, along with spatial connectivity to nearby wetlands, are thought to affect habitat suitability and species occupancy by influencing resource availability and movement pathways. This section discusses the relationships between wetland physical characteristics, landscape-scale connectivity, and spotless crake occurrence using logistic regression, permutation tests, and machine learning approaches to identify key predictors of presence within the study area.

Logistic Regression and Random Forest Analysis

Using a likelihood ratio test comparing the full logistic regression model to a null model indicated that the ability to explain spotless crake presence was not significantly improved by the included predictors ($X^2 = 4.12$, $df = 8$, $p = 0.85$). Predictors included wetland density and vegetation types. These findings support the conclusion that crake detection is challenging to explain using site-level habitat features alone.

Predicting Crake Presence by Wetland Shape

Effects of wetland connectivity on crake presence

The models indicated baseline odds of crake presence (odds ratio = 3.38, 95% CI: 0.81-18.47). The odds ratio for wetlands within 1 km was 0.77 (95% CI: 0.30–1.75, indicating a non-significant trend where increasing wetlands within 1 km were associated with a slight decrease in odds of crake presence. Similarly, wetlands within 5 km showed an odds ratio close to 1 (0.98, 95% CI: 0.72–1.40), suggesting very little to no effect on crake presence at this scale. The confidence intervals for both predictors included 1, which indicated no statistically significant relationship. The predicted probability plots confirmed that variation in wetland density at these scales had limited influence on the likelihood of crake occurrence in the studied wetlands.

Random Forest or Decision Trees (Explanatory, Non-parametric)

The Random Forest model identified wetland vegetation area and total wetland area as the most important predictors of spotless crake presence, with closely matched variable importance scores at the top of the ranking. These were followed by the number of wetlands within a 5 km radius, which suggests broader spatial context is an important indicator. Moderately important predictors included perimeter length, wetland shape, and number of wetlands within a 1 km radius. Vegetation type variables all ranked in the lower half of importance, which indicates that spatial characteristics have a stronger influence on crake presence than vegetation composition.

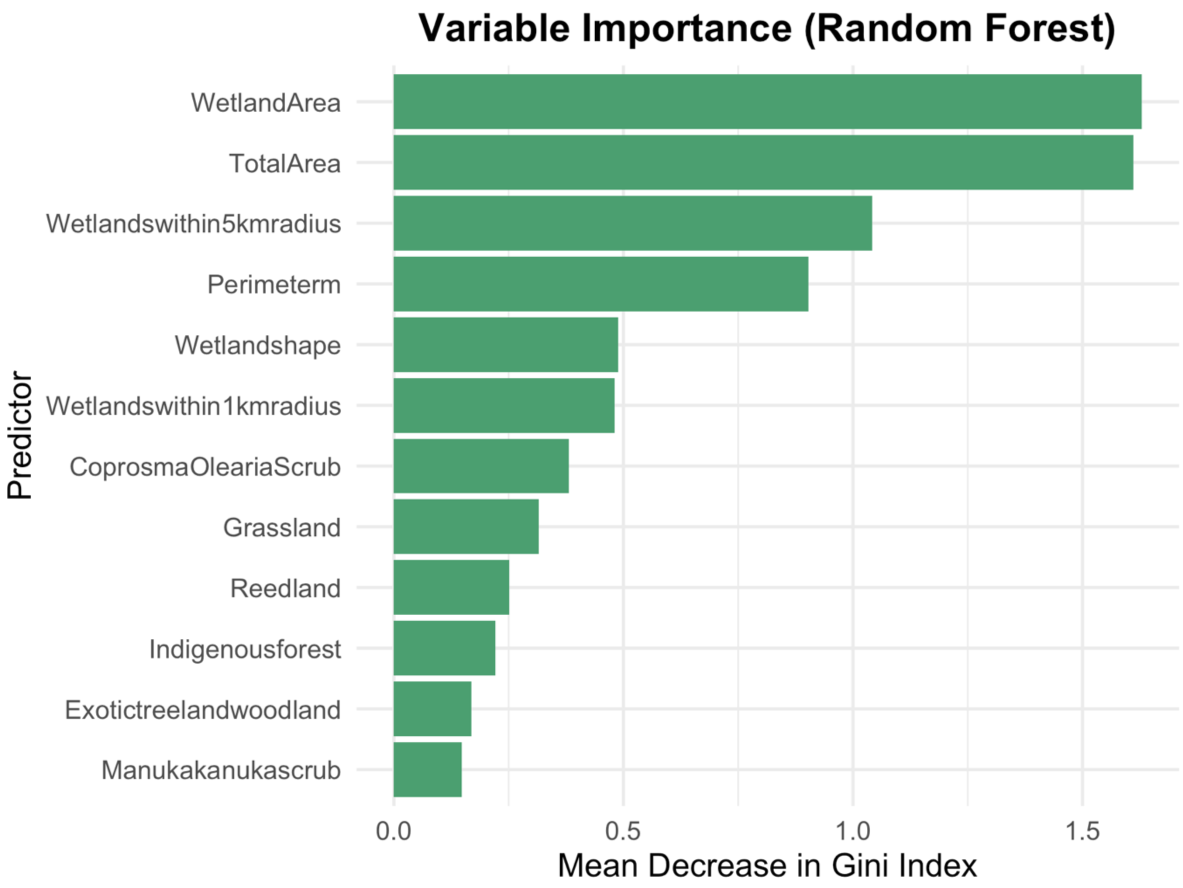


Figure 3-5. Random Forest variable importance for spotless crake presence

These findings underscore the potential ecological significance of wetland morphology, particularly shape and edge characteristics, in providing suitable habitat for spotless crakes. The Random Forest results complement the logistic regression analyses and highlight avenues for further research into how specific wetland physical attributes influence crake distribution.

Discussion

This study investigated the environmental and habitat features influencing the presence of spotless crake across a range of wetlands. Using a combination of statistical and machine learning approaches – including logistic regression and Random Forest analysis – I evaluated key habitat characteristics potentially associated with crake occurrence and their relative predictive power. While broad wetland-level variables such as area, perimeter, and shape did not clearly predict crake presence, finer-scale features, particularly dense reedland vegetation, appeared more relevant for supporting cryptic species like the spotless crake. These findings provide new insights into the ecological preferences of this cryptic marsh species and inform future monitoring and management strategies aimed at conserving suitable wetland habitats.

While the dataset provides a reliable description of the conditions in which crakes were detected, there are two key limitations in analyses attempting to identify discriminating habitat factors. First, some sites where crakes were not recorded may have, as a result of imperfect detection, supported the species resulting in potentially biased results. Second, the analyses were constrained by limited survey numbers – only 22 independent wetland sites were surveyed which reduced the ability to detect subtle relationships between habitat variables and crake presence.

Despite the limitations, the analyses revealed important information about crake habitat use. Crakes were detected in wetlands of varying sizes, including relatively small sites, indicating that even modest wetland areas can support the species. Most crake-occupied wetlands were not necessarily close to other wetlands, which suggests that wetland connectivity is not a key factor in presence. Vegetation composition at crake sites was dominated by dense emergent vegetation such as reedland. Reedland was positively associated with crake presence, while woody scrub and grassland were less commonly associated with crake detections. These results indicate that crakes may be flexible in terms of wetland size and isolation but may preferentially occupy sites with structurally dense vegetation that provides cover and foraging opportunities.

To examine differences between sites with and without crakes, we first conducted univariate permutation tests on measured habitat factors such as wetland area, perimeter, and connectivity. These tests found no statistically significant differences between crake and non-crake sites, though sites where crakes were not detected were with the exception of a single large wetland) smaller than crake-occupied sites. Multivariate analyses, including logistic regression and Random Forest models, similarly did not identify strong predictors of crake presence. Logistic regression produced no significant results, likely from the small sample size and limited statistical power of the dataset. These results suggest that measured habitat factors alone may not clearly discriminate crake presence, highlighting the species' flexibility and the challenges of detecting subtle habitat associations in data-limited species.

Random Forest provides a flexible, non-parametric approach to exploring habitat associations and highlighted several ecologically meaningful patterns. Both total wetland area and wetland vegetation area emerged as important predictors of crake presence, consistent with the expectation that larger, vegetated wetlands offer greater habitat complexity, more stable hydrological conditions, larger potential population sizes, and buffering from edge effects. Wetlands within 5 km also appeared somewhat influential, suggesting either a metapopulation dynamic, where birds move between sites, or reflecting the spatial distribution of wetlands in the region, where many occur along the coastal dune belt. These results reinforce long-standing ecological theory that wetland size influences species persistence, while also highlighting the species' flexibility—although larger areas provide clear benefits, small and isolated wetlands should not be dismissed as unsuitable. Such sites may act as stepping stones or seasonal refuges, contributing to broader metapopulation dynamics.

Surprisingly, vegetation categories were ranked low in importance by the Random Forest analysis. This likely reflects the limitations of the dataset, as vegetation was recorded only as presence/absence rather than as a continuous measure of cover or extent. In addition, the vegetation type most commonly associated with crake sites was also the most widespread overall, meaning it did not strongly discriminate between sites with and without crakes. While vegetation clearly plays a role in habitat suitability, the coarse resolution of the data limited its ability to emerge as a strong predictor in the modelling.

Overall, the analyses do not allow us to pinpoint definitive causes of crake presence or absence, but several patterns emerge that are consistent with ecological expectations and prior work. Larger wetlands appear more likely to support crakes, although detections in smaller sites show that extensive area is not a strict requirement. At the landscape scale, connectivity may be beneficial but crakes were also found in isolated sites. Vegetation patterns indicate that reedlands are particularly important, aligning with older studies that have highlighted the value of dense emergent vegetation for this species. Kaufman's work at Pukepuke Lagoon (Kaufmann 1988), for example, also emphasised the role of reed-dominated habitats in supporting crake populations. These findings suggest that while spotless crakes display some habitat flexibility, wetland size, landscape context, and the availability of reedland are likely to be key features influencing their distribution.

Overview of Modelling Approaches

To investigate the environmental factors influencing spotless crake presence across wetlands, this study employed a suite of statistical and machine learning models. **Logistic regression** was initially used to test specific hypotheses about the relationship between crake occurrence and habitat variables, and a Random Forest model provided a non-parametric, explanatory approach to assess variable importance without assuming linear relationships.

Both modelling frameworks offers different strengths and limitations. While logistic regression allows for interpretable effect sizes, it is sensitive to multicollinearity and sample size. In contrast, Random Forest are better suited to complex datasets with many interrelated predictors, though they offer less straightforward interpretability. Together, these two approaches provided a robust analytical framework for identifying patterns in crake habitat use and assessing the relative importance of different wetland characteristics. Despite some variation in findings between methods, several consistent themes emerged.

Wetland size and perimeter are often assumed to influence habitat suitability for wetland-dependent species due to their effect on resource availability and the degree of edge exposure. It is often assumed that larger wetlands support greater biodiversity due to increased habitat heterogeneity and lower vulnerability to disturbance, while more complex perimeters support high levels of diversity in the edges and transitional zones. Previous studies have highlighted the influence of wetland size and perimeter on habitat quality for waterbirds. Cerda-Peña (2023) investigated the importance of wetland habitat area for waterbird species-richness. A review of studies investigating this found that, in most cases, habitat area is a significant predictor of species richness. Seventy percent of the 40 reviewed studies identified area as an important variable, with a strong average effect size (r = 0.81). Many studies reported a positive correlation between area and richness, though few investigated the specific shape of this relationship. Additionally, 30% of the studies emphasized the importance of other habitat variables along with area, determining that wetland area alone is insufficient for conservation planning.

Unlike traditional statistical models that assess predictors independently and rely on assumptions such as linearity and significance testing), Random Forests are more useful for detecting complex, non-linear relationships and establishing connections between variables. This technique is useful when modelling challenging ecological patterns, including modelling cryptic or low-density species where sample sizes are often limited and species detections is especially difficult. The Random Forest is especially good due to its capacity to integrate available predictors and solve how to reduce classification error, whether or not they are individually statistically significant.

Reedland, sporting dense, emergent vegetation, has been identified as an ideal habitat for cryptic wetland rallids. These habitats provide essential concealment and suitable breeding or foraging grounds for such species. In New Zealand, the spotless crake predominantly inhabits freshwater wetlands dominated by dense emergent vegetation, particularly raupō. They may forage on open mud near dense vegetation but are quick to retreat when disturbed (Fitzgerald 2023). Additionally, studies have shown that spotless crakes require large, continuous blocks of tall emergent plants with an understorey of sedge for nesting. At Pukepuke Lagoon, raupō was identified as a preferred nesting substrate, with sedges like *Carex secta* used for nesting (Kaufmann 1987).

The relationship between spotless crakes and reedland is not well understood, but there are various articles that support this connection. Reeds are a type of plant that are characterised by their long, slender stems and flat, narrow leaves. Valkama (2008) investigated the impact of reed management on wildlife by conducting a meta-analytical review of European studies. Reed management, referring to harvesting, burning, moving and grazing, was found to have a significant negative impact on invertebrate community, and reduced abundance of passerine birds by about 60% (Valkama 2008). This study highlights the importance of reedland in wetland ecosystems. A study into reed cut, habitat diversity and productivity in wetlands further affirmed this. It was found that cutting reedland back decreased habitat diversity and structural heterogeneity (Deák 2015). Number of plant species and all measures of habitat diversity including the number of patches, vegetation types and the length of vegetation margins had lower scores in cut wetlands than in unmanaged ones. They found that unmanaged wetlands had high habitat diversity and accumulated biomass. Additionally, this biomass accumulation led to increased structural heterogeneity. These results underscore the significance of reedbeds in wetlands for the support of rail species.

The importance of broader-scale connectivity may reflect the local-scale dispersal ability of the spotless crake.

Understanding Wetland Suitability Through Vegetation Composition and Structure

Vegetation structure plays an important role in shaping the ecological function and biodiversity of wetland ecosystems. Structural vegetation characteristics such as height, density and spatial arrangement influence microclimatic conditions, water retention, predator-prey dynamics, and the availability of foraging and nesting sites. These factors play a crucial role in wetlands, where the relationship between hydrology and vegetation creates a mosaic of habitat niches.

For cryptic wetland-dependent species such as rails and crakes, vegetation structure is especially critical. These birds rely on dense cover for protection, nesting, and movement. For instance, black rails (*Laterallus jamaicensis*) occupy shallow permanent wetlands with dense cattails, rushes, sedges, or wetland grasses, rarely venturing into open areas. Similarly, small European rails, found in shallow-water zones, inhabit dense sedge-dominated habitats and can thrive in wetlands <1 ha when conditions are favourable (Swiss Ornithological Institute 2025). Survival in little crakes (*Porzana parva*) and water rails (*Rallus aquaticus*) has also been shown to increase significantly with vegetation height (Jedlikowski 2017).

As such, wetlands dominated by tall, emergent vegetation like reeds provide the concealment and microhabitats necessary for their survival. Further, vegetation that lacks vertical complexity may increase exposure to predators and reduce suitable habitat.

Wetland Morphology and Edge Effects

In addition to vegetation structure, the size, shape, and spatial complexity of wetlands influence habitat quality and availability for species that depend on wetland environments. The physical shape of a wetland influences ecological function at a broader spatial scale. The structure and size of fringing vegetation are essential for determining habitat suitability, as they impact interior habitat, hydrological complexity, and connectivity to adjacent habitats. These vegetative fringes are subject to edge effects like predation, human activity, and desiccation. For instance, irregular or elongated wetlands have more edge habitat in relation to their area, which may impact vegetation composition differently than compact and consistently shaped wetlands, which provide more buffered interior zones.

In this study, while the relationship was not statistically significant, wetland shape emerged as a potentially meaningful predictor of spotless crake presence, namely through the "long and wide" shape category. This finding suggests that wetlands with an elongated structure may provide a favourable balance of habitat features for cryptic species. It is possible that these shapes allow for extensive fringing vegetation (e.g., reedland) which supports foraging and nesting habitat. For elusive and sensitive birds like the spotless crake, vegetation and wetland structure may therefore influence overall habitat suitability for spotless crake. These findings highlight the importance of incorporating spatial geometry into habitat assessments and wetland conservation planning.

These findings are supported by previous research showing that wetland shape and edge complexity can enhance wetland-dependent bird habitat value. For example, Mora (2011) reported that higher perimeter-to-area ratios were significant predictors of bird diversity in prairie wetlands, indicative of greater edge complexity combined with emergent vegetation. Further, a study on another cryptic rail species, the water rail, displayed their reliance on dense reedbeds and varied shoreline edges. These emphases that both vegetation structure and spatial geometry contribute to habitat suitability (Jenkins 1995).

Our findings revealed that crake responses occurred in wetlands smaller than 25 hectares with perimeters under 3500 m. Wetland area and perimeter did not vary systematically with shape, indicating that shape alone does not capture meaningful differences in wetland size or edge complexity – factors that might influence habitat suitability for cryptic species like the spotless crake. These findings suggest that, although wetland shape was initially expected to be a relevant classification, it is unlikely to serve as a useful proxy for habitat quality or crake presence on its own.

Connectivity Patterns in Other Wetland Species

Many wetland-dependent species rely heavily on spatial connectivity. In the case of taxa such as waterfowl or herons—which are highly mobile—proximity to nearby wetlands can significantly influence movement, colonisation, and gene flow. Studies have displayed that higher densities of nearby wetlands can facilitate metapopulation dynamics and improve overall species persistence by enabling dispersal between patches (Gibbs 2000). In these studies, spatial connectivity buffers against local extinctions and enhances land-scale level resilience.

It is not obvious where the difference originates from, however it may lie in life history traits. Species with greater dispersal ability or seasonal migratory behaviour tend to benefit from clustered wetland habitats. In contrast to more generalist or mobile waterbirds, whose movements often respond to landscape-scale connectivity and wetland networks, the movement ecology of cryptic species like the spotless crake remains poorly understood. It is unclear what spatial scale of habitat network crakes rely on, or how far they disperse between wetlands. Preliminary radio-tracking studies by Emma Williams suggest that crakes have small home ranges and strong fidelity to dense, emergent vegetation patches, but broader-scale movements remain largely undocumented (Williams 2024). This reliance on dense vegetation and sensitive nature may limit their ability to move between sites.

Implications for Conservation and Monitoring

The findings of this study emphasise the importance of preserving and managing wetland vegetation structure, particularly reedland habitats, which appear to play a crucial role in supporting spotless crake populations. conservation efforts should prioritise maintaining both the quality and extent of dense emergent vegetation to provide essential cover and breeding habitat. While spatial connectivity between wetlands is often highlighted in landscape-level conservation, our results suggest that local habitat characteristics may be more influential for cryptic wetland birds with limited dispersal. Monitoring programmes should incorporate fine-scale assessments of vegetation composition and structure alongside broader landscape metrics to more accurately evaluate habitat suitability and species presence. Such an integrated approach will strengthen the basis for targeted management actions aimed at sustaining viable crake populations within fragmented wetland systems.

Chapter 4 – General Discussion

This study aimed to improve the understanding of the ecology and monitoring of the cryptic wetland bird, the spotless crake (*Zapornia tabuensis*) in the Manawatū-Whanganui region of Aotearoa New Zealand. I explored both the influence of environmental conditions on vocal response behaviour during acoustic playback surveys, and the species' habitat association across a range of wetland types. This study addresses key gaps in the ecological knowledge of this cryptic species and offer practical insights into improving detection and conservation outcomes.

In chapter two, I investigated how environmental factors influence the likelihood of detecting spotless crake presence during playback surveys. Using binomial and Poisson generalised linear mixed models, variables such as temperature, time of day, wind, and cloud cover were identified to influence detection probability and call rate. Specifically, temperature and time of day were the most influential predictors in the full dataset, while time of day replaced temperature in the confirmed crake sites dataset. Light level was observed to have inconsistent effects across the models and was determined to not be a reliable predictor of responsiveness.

In chapter three, habitat features associated with spotless crake presence were measured across a series of systematically surveyed wetlands. Habitat features of sites with confirmed crake populations were described, and while logistic regression models did not identify any significant predictors of crake presence, Random Forest analysis indicated that larger wetlands and those with greater connectivity within 5 km were more likely to have crakes. These results suggest that both local wetland habitat characteristics and broader landscape configuration can play roles in supporting crake populations.

Integrating Behaviour and Habitat: What Determines Crake Detectability and Occupancy?

The findings from my study illustrate that crake presence and detectability are governed at varying degrees by a combination of environmental and habitat factors, rather than any single variable. While vocal activity is somewhat sensitive to immediate weather and time of day, habitat associations indicate that crakes prefer wetlands dominated by dense emergent vegetation, particularly reedland. These features likely enable their cryptic behaviour and support nesting, while potentially contributing to vocal behaviour. Notably, the absence of strong landscape-scale effects (e.g., wetland shape or connectivity) indicates that spotless crakes may not be as strictly specialised as previously assumed. An important outcome of this study is that even small or isolated wetlands can support crake populations, provided that there is suitable vegetation. This flexibility may enhance both the species' persistence in fragmented landscapes and the effectiveness of monitoring efforts focused on fine-scale habitat features. This study also illustrated the need for further research due to their secretive nature and conditional vocal behaviour. These continue to challenge reliable detection and reinforces the need for refined monitoring protocols.

Conservation and Management Implications

Refined survey design:

These results provide crucial insight into wetland monitoring and conservation management. Playback surveys are effective and may not rely as heavily on environmental factors as previously thought. While their efficacy may be influenced by temperature, wind, cloud cover, and time of day, these factors may not have to be specifically aligned for surveys to have effective monitoring results. Surveys could be timed to align with early morning periods under mild, calm weather conditions to maximise detection rates. Repeated surveys are essential for reliably detecting cryptic species such as spotless crakes. Two independent surveys at a site would provide ~95% confidence that the spotless crake is absent if no detections occur.

Habitat restoration priorities:

Restoration efforts should prioritise the establishment or protection of reed-dominated wetlands, while minimising the presence of woody scrub in known crake habitats.

Recognising habitat flexibility:

While spotless crake are clearly associated with certain vegetation types, they may tolerate a broader range of conditions than initially believed. This insight can provide restoration groups with crucial information and the identification of suitable sites for reintroduction or protection.

Seasonality and Bird Vocalisations:

Seasonal variation is a well-established factor influencing bird vocal behaviour across a wide range of species and habitats. In many avian taxa, vocalisations are most frequent and conspicuous during the breeding season when calls and songs play critical roles in territory establishment, mate attraction, and pair bonding. This seasonal peak in vocal activity is often closely aligned with environmental cues such as photoperiod temperature, rainfall, and food availability which together signal the optimal time for breeding.

There are many studies establishing the relationship between environmental and temporal factors and bird vocal behaviour. Digby (2014) investigated these influences in the little spotted kiwi (*Apteryx owenii*), examining vocal activity over a three-year period. This study incorporated a range of variables including sex, time of night, season, weather, conditions and lunar cycle. Results demonstrated that vocalisations are highly important to kiwi, with all-weather variables significantly affecting call rates. Specifically, calling increased during periods of high humidity and ground moisture, while cloudy nights in the absence of moonlight were associated with significantly reduced vocal activity. These findings highlight the complexity of environmental influences on vocal behaviour and underscore the importance of considering multiple temporal and climatic factors when interpreting calling patterns in cryptic bird species.

In temperate and subtropical regions, including New Zealand, spring and summer months can result in behavioural changes. Longer days and warmer temperatures during this period can stimulate hormonal changes that drive increased calling and singing behaviour. For cryptic or secretive species like the spotless crake which are rarely seen and are primarily detected by sound, seasonal vocal patterns are particularly important for monitoring. Surveys conducted outside the peak calling season may substantially underestimate presence or abundance due to reduced vocal activity. To demonstrate the relationship between subtropical birds, breeding season, and vocalisations, studies have shown that many species exhibit increased vocal activity during the warmer months when breeding typically occurs. In these environments, seasonal cues such as temperature rainfall and day length act as triggers for reproductive behaviour, often resulting in heightened vocal output used for mate attraction and territory defence. This pattern is particularly evident in species inhabiting wetland and forest ecosystems where dense vegetation limits visual detection, and vocalisations become the primary means of communication.

One such study that demonstrates this relationship is Krishnan’s (2019) investigation into acoustic community structure and seasonal turnover in tropical South Asian birds. This research explored how the presence of migratory species influences the composition and dynamics of avian acoustic communities across seasons. Krishnan clarified the relationship between seasonality and vocal activity by examining how temporal changes in species composition, particularly the arrival and departure of migrants, affected the structure and complexity of acoustic signalling within bird communities. Krishnan observed that the influx of winter migrants to a tropical dry forest bird community in India is accompanied by a change in species composition of the acoustic community. He also found that the acoustic community remains overdispersed in acoustic niche space, meaning that species tend to avoid overlapping in their vocal frequencies and temporal patterns even as community composition changes seasonally. This overdispersion suggests a level of acoustic partitioning that reduces signal interference and allows for more effective communication among species. Such structuring highlights the importance of acoustic niche dynamics in shaping community interactions and supports the idea that seasonal shifts in vocal activity are not only biologically driven by breeding cycles, but also shaped by ecological pressures to maintain distinct signalling spaces. Krishnan's study highlights the dynamic nature of bird vocal communities in tropical environments, demonstrating that seasonal changes and species turnover influence acoustic structure, while consistent niche partitioning underscores the ecological importance of vocal differentiation for effective communication.

This understanding of acoustic community dynamics highlights how seasonal changes and ecological factors, such as the presence of migratory species, can influence calling rates, making vocalisations particularly sensitive to temporal patterns and environmental conditions during playback surveys. Several studies have shown that response rates to playback calls are significantly higher during the breeding season compared to nonbreeding periods (e.g., (Rios-Chelen 2007, Barnes 2012, Vrezec 2018), underscoring the need to align survey timing with the species vocal activity cycle. Inconsistent detection across seasons can also complicate population assessments if survey timing is not standardised. For instance, Nebel and McCaffery (2003) documented vocalisation activity of breeding shorebirds in northern and western Alaska, finding that the number of calling individuals decreased throughout the season. This highlights the importance of timing weather and environmental factors in influencing the number of birds detected during surveys.

Understanding the seasonal dynamics of vocal behaviour not only enhances survey effectiveness but also provides valuable insights into the reproductive phenology and ecological requirements of a species. Recognising peak calling periods is essential for accurately assessing species distribution, habitat use, and population trends, particularly for elusive or declining species that rely on vulnerable wetland ecosystems. For example, Slagsvold (1977) analysed seasonal song patterns for over 20 bird species in South Norway's forested areas based on 700 surveys conducted from 1968 to 1974. His analysis revealed a strong relationship between song activity and the breeding cycle, with maximum song activity occurring just before egg-laying. Additionally, Slagsvold identified a significant correlation between the timing of vocalisations in early bird species and environmental factors such as temperature, snowmelt, and the phenophases of birch and key invertebrates. These findings further support the concept that bird vocalisations are intricately linked to seasonality at multiple ecological levels including environmental phenology.

In our study, responses were higher in October, November and December. This could indicate that the breeding season had not yet fully commenced or that birds were less responsive to playback outside of peak reproductive activity. Interestingly, a small number of responses were also detected in September and December suggesting that some individuals may exhibit early or extended calling activity, possibly in response to favourable local conditions such as wetland water levels or vegetation structure.

There are numerous studies highlighting changes in response rates depending on seasonality, including those mentioned above. However, in our study some responses were observed as early as September, a period typically considered preseason. This suggests that while most of the vocal activity is concentrated in the peak breeding months, there may still be sporadic calling outside of the expected seasonal window. These early responses could indicate varying individual or site-specific behavioural patterns potentially influenced by local environmental conditions or the early stages of breeding activity.

Bird vocalisations serve a wide range of functions, and their purpose can vary significantly depending on species context and environmental conditions. During the breeding season many male birds vocalise to attract mates using songs or specific calls to signal their fitness territory quality and genetic suitability. These calls play a crucial role in female mate choice as females often assess the quality and consistency of vocalisations when selecting a partner. Vocalisations are also central to territorial defence. By calling frequently and loudly, birds establish the boundaries of their territory and deter rival males often avoiding physical conflict by signalling dominance acoustically. In addition to reproductive and territorial functions, birds use vocalisations to communicate with conspecifics for a variety of purposes such as locating food sources coordinating group movements or alerting others to potential threats.

Temporal Variation and Survey Design

These seasonal differences underscore the need to incorporate temporal variation into the design of playback survey protocols for the spotless crake (Gaston 1994). Given the pronounced fluctuations in vocalisation patterns across different months, it becomes apparent that the timing of surveys can significantly affect the accuracy and reliability of detection rates. By focusing survey efforts on peak months such as January and February which coincide with periods of increased vocalisation, researchers are more likely to detect the presence of this elusive species and obtain a clearer understanding of its relative abundance. However, the occurrence of early and late responses outside of the peak months suggests that relying solely on this narrow time frame may overlook important aspects of the species activity.

To capture a fuller picture of the spotless crake's seasonal behaviour, it is essential to extend monitoring efforts across a broader time window encompassing both the peak and the shoulder months before and after it. For instance, conducting surveys in late spring and early autumn could provide critical information about the early onset of breeding activity or post-breeding behaviour when vocalisations may begin earlier or persist longer than anticipated. These extended survey periods would allow for the detection of shifts in vocalisation intensity and timing, helping to map out the full extent of the crake's activity throughout the year.

By broadening the temporal scope of surveys, researchers could more accurately track the fluctuations in the species behaviour accounting for variations that may be linked to environmental factors such as temperature habitat availability and food resources (Martin 2017). These seasonal shifts in activity could also help identify critical windows of vulnerability or high activity that are important for the conservation of the species. Additionally, incorporating a variety of survey periods would provide a more nuanced understanding of how different environmental and ecological conditions influence vocalisation patterns. This approach would ultimately allow for more targeted conservation interventions as monitoring efforts could be strategically aligned with the times when the species is most active or most vulnerable.

In summary, while focusing on peak months for survey efforts can improve detection rates, expanding the survey window to include the shoulder months will provide a more comprehensive view of spotless crake behaviour. Such an approach will ensure that we capture the species full activity range and contribute to more accurate estimates of presence and relative abundance, thereby enhancing the effectiveness of both monitoring and conservation strategies.

One challenge in monitoring cryptic species is the significant amount of time researchers must dedicate to each step of the survey process. This can be costly due to the time spent in the field and on data analysis and it can create logistical challenges when researcher availability is limited. Consequently, the quality and quantity of data collected may be compromised potentially impacting the effectiveness of conservation efforts (Barata 2017). The use of AI in cryptic species monitoring could be an effective way to enhance monitoring and reduce costs in the long term.

AI has the potential to significantly enhance crake monitoring especially given their cryptic and elusive nature. By utilizing automated call recognition, AI could identify and classify crake vocalizations from audio data reducing human involvement and the time spent on manual analysis. This would not only increase detection accuracy but also minimize human error. AI could also analyse environmental and survey data uncovering patterns in crake behaviour and habitat use. Furthermore, AI-powered image recognition could help identify crake nests or individuals in camera trap images, easing the workload for researchers when reviewing large datasets. Additionally, AI could predict population trends contributing to more effective conservation strategies. Integrating AI with drone or autonomous monitoring systems would facilitate largescale surveys in remote wetlands. However, for AI to be effective its integration with traditional methods should be approached thoughtfully, ensuring models are trained on sufficient data to deliver reliable results. Ultimately, AI, when combined with conventional techniques, has the potential to enhance crake monitoring and improve conservation outcomes.

Drivers of Seasonal Vocal Activity

While environmental variables such as temperature, habitat conditions, and breeding status have been identified as potential drivers, the complexity of how these factors interact remains largely unexplored. It is possible that no single variable acts in isolation, rather the interaction between multiple ecological and environmental factors shapes the vocalisation patterns observed throughout the year.

For instance, while temperature may influence calling behaviour, it's effect could be modified by other factors such as water levels in the wetland. Wetland water levels fluctuate seasonally which in turn affects the availability of suitable habitat and food sources. During periods of low water levels, the concentration of food might become more predictable which could encourage more frequent vocalisations as the crakes compete for resources or establish territories. Conversely, high water levels might lead to the dispersal of food resources, potentially leading to reduced vocal activity. Similarly, dense vegetation could provide cover depending on the time of year influencing the crake's willingness to call. During the breeding season, when food is abundant and vegetation is lush, the crake may be more likely to vocalise, while during less optimal conditions, such as during drought or after vegetation has been altered, calling activity may be reduced.

Breeding status is another critical factor that may influences vocalisation. During the breeding season, individuals may increase vocalisations to attract mates or defend territories, but the timing of this increased activity could vary depending on the environmental conditions mentioned earlier. Understanding the specific conditions under which the crake is most likely to engage in vocal activity during the breeding season—such as the availability of food, temperature ranges, and vegetation structure—will enhance our ability to predict when the species will be most detectable.

Exploring these interactions in greater detail will help refine our understanding of how seasonal vocalisation patterns are shaped by a combination of biotic and abiotic factors. This insight is crucial for improving the design of survey protocols. By accounting for these interactions, we can create more accurate and reliable detection methods that consider the full range of conditions under which the spotless crake is most likely to vocalise. For example, incorporating a multifactorial approach that considers temperature water levels, food availability, and vegetation density could help identify the most optimal times for surveys improving detection rates across seasons.

Furthermore, understanding these underlying drivers of vocal activity will not only improve survey design but also provide valuable insights for the conservation and management of wetland habitats. Identifying the key environmental factors that drive crake activity will help target conservation efforts to the most critical periods, ensuring that resources are allocated effectively to protect the species during its most vulnerable times.

In conclusion, exploring the interactions between temperature, habitat conditions, and breeding status—and how these factors collectively influence the seasonal vocalisation patterns of the spotless crake—will provide a more nuanced understanding of the species ecology. This research is vital for refining monitoring techniques and ensuring that conservation strategies are both effective and timely.

Breeding Status and Vocal Activity

Research into the relationship between the spotless crakes breeding status and its vocal activity is crucial for enhancing our ability to monitor and protect this species. Breeding behaviour is often a key driver of vocalisation patterns in many bird species, and the crake is no exception. During the breeding season both males and females of many species, including the crake, typically engage in increased vocal activity. For males, vocalisations are often used for territory defence and mate attraction while females may also respond to vocal cues during courtship. This heightened vocalisation can offer valuable opportunities for detection, making the timing of surveys critical for accurately assessing the species presence and abundance.

Understanding how different stages of the breeding cycle affect vocal activity is essential for developing targeted survey protocols. For example, there may be periods within the breeding season—such as the establishment of territories, mate attraction, or post-hatching care—when vocal activity peaks. Alternatively, certain stages may see a reduction in calling behaviour particularly after the nesting phase when the focus may shift towards chick-rearing and less territorial calling. Knowing when these shifts occur would allow survey efforts to be timed more effectively, ensuring that monitoring is aligned with periods of heightened vocalisation. This temporal precision could lead to more reliable estimates of population size and distribution which are critical for effective conservation planning.

Moreover, understanding the influence of breeding status on vocalisation patterns would have broader implications for the conservation and management of the spotless crake. Many wetland-dependent species, including the crake, are vulnerable to disturbances during the breeding season whether from habitat degradation, human activities, or natural changes in environmental conditions. If certain periods of the breeding cycle are linked to a significant increase in vocal activity, it may be possible to use these times as windows for targeted conservation efforts such as habitat restoration or mitigation measures to reduce human impact.

Understanding the dynamics of breeding cycles and their impact on vocalisation can help inform disturbance mitigation strategies. If disturbances such as construction activities or water level fluctuations occur during the crakes peak breeding period, these activities could disrupt breeding success. By identifying the peak breeding windows through vocalisation patterns, conservation, managers can time interventions to avoid disturbing the species during these sensitive periods. For example, scheduling wetland restoration or management activities outside of the crakes breeding season would allow the species to breed undisturbed improving reproductive success and supporting the populations long-term viability.

Research into the role of breeding status in vocalisation patterns could have important implications for the broader management of wetland ecosystems. By understanding how breeding conditions influence the crakes use of habitat and its vocal activity we can better anticipate changes in the availability and quality of suitable wetland habitats. These insights can guide restoration projects to improve habitat suitability at critical times of year enhancing the chances of successful breeding and population growth.

Microhabitat Conditions and Detectability

Further investigation into the influence of microhabitat conditions—such as vegetation type, water depth, and shelter availability—on spotless crake vocalisation is essential for refining survey methodologies and improving our understanding of species detectability. Wetland environments are highly heterogeneous with microhabitats offering different resources and protection for the crake. For example, dense vegetation may provide more shelter from predators, but it could also make vocalisation detection more challenging. Conversely, areas with sparse vegetation might be more exposed, increasing the likelihood of detecting vocalisations but potentially offering less shelter and food availability.

Water depth is another critical factor as it can influence the distribution of food sources such as aquatic invertebrates and small fish which, in turn, may affect the crake's activity and vocalisation patterns. Shallow areas may offer better feeding opportunities, and the crake may be more likely to vocalise in these environments either due to increased resource availability or heightened territorial activity. On the other hand, deeper areas might provide greater protection but could limit feeding opportunities, leading to differences in calling behaviour and detection rates.

By incorporating microhabitat conditions into future studies, we can gain valuable insights into how spatial variability within wetlands affects the detectability of cryptic species like the spotless crake. For example, identifying key microhabitats where crakes are more likely to vocalise, could help to focus survey efforts in areas with higher detection probabilities improving the efficiency of monitoring programs. Additionally, understanding these habitat preferences could inform habitat restoration and management practices, ensuring that wetlands provide the necessary conditions for crake populations to thrive.

Examining the relationship between microhabitat conditions and the vocalisation behaviour of the spotless crake is an important step toward improving both monitoring efforts and conservation strategies. By accounting for the spatial variability in wetland environments we can ensure that survey methods are more effective and that management practices are better tailored to support the needs of this elusive species.

Seasonality AND Playback Surveys:

The accuracy of playback surveys is strongly affected by seasonal factors. One significant limitation is the inconsistency in vocal responsiveness throughout the year. Birds are generally more likely to respond to conspecific calls during the breeding season when vocalisations serve essential functions such as territory defence, mate attraction, and coordination of nesting activities. Outside of this period, particularly during the nonbreeding season, birds may reduce or completely cease vocal activity resulting in lower detection rates even if individuals are present in the habitat. This seasonal decline in responsiveness can lead to false negatives and underestimation of population size or occupancy.

Additionally, phenological shifts driven by climate variability—such as early or delayed onset of breeding—can cause interannual variation in calling behaviour, further complicating the timing of playback surveys. If surveys are not aligned with a species peak vocal activity window, comparisons across years or regions may lack reliability. Moreover, certain weather-related seasonal variables—such as temperature wind rain and light availability—also affect calling rates. For instance, surveys conducted during cooler or windier conditions may yield fewer responses due to reduced calling activity or impaired sound transmission.

Habitat changes related to seasonality also pose a limitation. Dense vegetation during the breeding season may muffle playback sound or affect how calls travel. Furthermore, in migratory or partially migratory species, individuals may be absent during specific times of the year leading to misinterpretation of habitat use if seasonal presence is not accounted for.

Ultimately, without accurately accounting for seasonal influences playback surveys risk providing incomplete or misleading data. Standardising survey timing to align with known peaks in vocal activity incorporating repeated measures across seasons and integrating environmental data can help mitigate these limitations and enhance the interpretive power of playback-based monitoring.

Interpreting the Lack of Significance in Wetland-Level Variables

It is possible that larger or more structurally complex wetlands do not necessarily provide the dense, emergent vegetation preferred by spotless crakes. Instead, crakes may respond more directly to specific vegetation types or microhabitat features, rather than broader spatial characteristics of the wetland. This highlights a limitation of our study: using coarse spatial metrics alone may be insufficient to predict the presence of highly specialised, cryptic fauna, emphasising the importance of incorporating vegetation composition and structure into wetland assessments.

These findings contrast with patterns often observed in studies of more generalist or mobile wetland bird species, where wetland area and perimeter are frequently linked to higher species richness and habitat use. For example, a paper discussing how habitat patch size and shape influence bird species' nest success and habitat suitability emphasises that edge effects and patch geometry can strongly affect cryptic and sensitive bird species (Batary 2004). Further, an article by Kingsford and Porter (1994) reviews habitat characteristics influencing waterbird diversity, highlighting that patch size and shape matter but other variables like vegetation structure can be more critical for specialist species such as, while wetland morphology plays a crucial role in habitat suitability, the specific requirements of a cryptic and specialist species like the spotless crake mean that vegetation structure and microhabitat features may have a stronger influence on their presence than landscape-scale patch metrics alone (Kingsford 1994).

In addition to the potential for failing to detect crakes that were present, it is also possible that spotless crakes occupy some wetlands intermittently. As such, sites where the species was not recorded during surveys may in fact provide suitable habitat and could support crakes at other times of the year. This temporal variation in site use adds further uncertainty to distinguishing true absence from non-detection, reinforcing the need for caution in interpreting survey data and highlighting the value of repeated and seasonally distributed monitoring efforts.

Role of environmental conditions in wetlands

Climate plays a fundamental role in shaping the dynamics of wetland ecosystems, with temperature acting as a key driver of ecological processes. Wetlands are particularly vulnerable to climatic fluctuations due to their dependence on water levels, seasonal cycles, and delicate biological interactions. Shifts in temperature can significantly alter hydrological regimes, affecting the extent, depth, and duration of wetland inundation. These changes influence plant growth, nutrient cycling, and the availability of habitat for wetland-dependent fauna. For species like the spotless crake which rely on specific wetland conditions for breeding and foraging, even modest temperature changes could have cascading effects on behaviour and survival. Warmer temperatures may accelerate the onset of the breeding season and increase metabolic rates, potentially intensifying vocal activity and altering foraging patterns. However, extreme temperatures—either hot or cold—can disrupt these patterns, suppress reproductive activity, or shift the timing of key life history events. At the community level such climatic shifts may lead to changes in species composition, competition dynamics, and ecosystem function. As climate variability increases, understanding how temperature and other environmental variables shape wetland processes is critical for informing conservation and monitoring efforts in these sensitive and often fragmented habitats.

Londe (2024) explored the impacts of climate change on wetland ecosystems with a particular focus on wetland inundation patterns. The study highlighted a significant gap in current research regarding how these changes may affect migratory species, especially in relation to seasonal shifts in wetland availability. Using a range of climate models, Londe predicted that the average number of inundated wetlands is likely to decline during both spring and autumn migration periods. While the extent of these declines varied depending on the climate model and ecoregion, the overall trend indicated that most regions are expected to experience dry years with increasing frequency. These projected reductions in wetland availability pose a serious concern for wetland-reliant birds.

Temperature plays a significant role in the distribution and movement patterns of wetland species. As temperatures fluctuate, species may shift their locations in search of more favourable conditions such as better foraging opportunities or more suitable microhabitats. Understanding how temperature influences the behaviour and movement of species like the spotless crake is essential for accurate monitoring as it can help researchers predict when and where to conduct surveys for the best chances of detecting vocal responses.

In the context of playback surveys, temperature can also affect the likelihood of a species responding to calls. For cryptic species like the spotless crake which rely on subtle vocalisations for communication and territory defence, temperature-induced changes in vocal behaviour must be considered when designing surveys.

Temperature-related shifts in activity or vocalisation patterns could explain why certain species do not respond to playback calls during particular times or environmental conditions, making it essential for researchers to factor in temperature when analysing survey data and interpreting results. Findings from research of other cryptic wetland birds are consistent with ours, which often exhibit limited dispersal and strong site fidelity due to their secretive nature and habitat specialisation (e.g., Mora, Mager III et al. (2011)).

Time of day is another critical environmental factor that significantly influences the behaviour and vocalisation patterns of wetland species. Many species, including the spotless crake, are known to exhibit distinct activity patterns that vary depending on the time of day. This is often tied to factors such as temperature, light levels, and predation risk which fluctuate throughout the day and night. For cryptic species like the spotless crake, nocturnal and crepuscular activity is common, with many species being more active during the low light levels of dawn or dusk. These species have adapted to take advantage of reduced visibility during these times to avoid predators while foraging or engaging in other critical behaviours such as territory defence and mate attraction. As a result, the time of day can have a significant impact on the detection of species through acoustic monitoring.

During certain times of the day, such as in the early morning or late evening, species may be more likely to vocalise, increasing the chances of detecting their presence during playback surveys. For instance, many birds and amphibians tend to call more frequently at dawn and dusk, coinciding with their peak activity periods. Understanding these patterns is vital for effective survey planning as it helps researchers determine the optimal time windows to conduct playback surveys and maximise the chances of eliciting responses.

Additionally, the time of day can influence the reliability of playback survey results. If surveys are conducted during times when a species is less active there may be an increased risk of receiving false negatives, where the species is present but does not respond to playback calls due to reduced vocalisation activity. This is particularly important for species that exhibit peak vocalisation periods tied to specific times of the day as conducting surveys outside these windows may lead to underreporting or misinterpretation of species presence.

In summary, time of day is an essential consideration for wildlife monitoring particularly when conducting playback surveys for cryptic species like the spotless crake. By aligning survey efforts with species natural activity patterns, researchers can increase the likelihood of obtaining accurate data on vocalisation behaviour and presence ultimately contributing to more effective conservation and management strategies.

The strength of this correlation indicates a potential environmental coupling between these two factors which may have implications for both survey detectability and the behaviour of cryptic wetland species such as the spotless crake.

Detection Limitations in Spotless Crake Monitoring: A Broader Perspective

Monitoring cryptic wetland species such as the spotless crake presents significant challenges due to their elusive behaviour, low detectability Longterm Monitoring and Interannual Variability and habitat-specific activity patterns. Detection is further complicated by the species reliance on dense emergent vegetation and its tendency to vocalise sporadically, often influenced by environmental conditions (Borkin 2023).

One of the primary limitations in spotless crake monitoring is the use of presence-only data which do not account for false absences, when a species is present but goes undetected. This can lead to biased assessments of habitat use and distribution particularly in sites where environmental conditions survey timing or observer experience reduce the likelihood of detection (MacKenzie 2002). For instance, factors such as windspeed, temperature, time of day, and cloud cover have been shown to influence crake vocalisation and detection probabilities (Williams 2016). Without accounting for these variables, surveys risk underestimating the species' true presence and misrepresenting habitat suitability.

A further limitation of this study lies in the treatment of vegetation data as a presence/absence rather than quantitative measures of cover or density. While reedland emerged as an important predictor, recording only its presence does not capture enough information about extent or structure within wetlands, limiting the ability to detect fine-scale habitat associations. Further, the absence of detailed microhabitat information, such as vegetation height, density, or hydrological conditions, constrains interpretation of habitat suitability. Future work that quantifies vegetation composition and structure more effectively, for example through percentage cover estimates or high-resolution habitat mapping, would provide greater insight into the habitat requirements of this cryptic species.

It is important to acknowledge that the choice between analysing all surveyed sites versus only confirmed sites carries implications for the interpretation of detection rates. Given the cryptic behaviour of spotless crakes, non-detection cannot be assumed to represent true absence, and sites without detections may still support the species. Consequently, detection rates calculated across all sites are valid, while those restricted to confirmed sites risk inflating apparent presence by excluding locations where crakes were present but undetected. Consideration of both perspectives therefore provides a more balanced and cautious understanding of detection patterns, recognising that neither approach yields complete knowledge of the species' distribution.

Additionally, limiting surveys to sites with known presence can reinforce detection bias as it excludes habitats where crakes may occur but have not yet been recorded (Gu 2004). This restricted approach not only reduces the generalisability of findings but may also overlook ecologically significant wetlands that support undetected populations. Over time this could lead to an inaccurate understanding of the species ecological requirements and limit the effectiveness of conservation strategies (Yoccoz 2001).

To address these limitations, it is essential to incorporate methods that account for detection probability and include both presence and absence data in survey designs (Yoccoz 2006). Repeated surveys, use of occupancy modelling and inclusion of environmental covariates can help disentangle true absences from non-detections, providing a more reliable understanding of spotless crake distribution and behaviour. Such approaches are particularly important in light of increasing environmental variability due to climate change and habitat modification, which may further influence species detectability and distribution over time (Elith 2009).

Exploring the Consequences of Presence-Based Data on Wetland Species Research

Presence-based (or presence-only) data are commonly used in ecological studies due to their accessibility particularly for cryptic species like the spotless crake. However, relying solely on detections can introduce substantial limitations. Presence-only data assume that species are absent from areas where they are not recorded which can result in detection bias (Yackulic 2013). For elusive species like the spotless crake which vocalise irregularly and inhabit dense vegetation, this assumption risks overlooking individuals that are present but not detected leading to underreporting of their actual distribution.

Such detection failures can stem from several factors, including weather conditions, time of day, vegetation density, or seasonal behavioural changes (O'Donnell and Williams 2015). For example, the spotless crake may not respond to playback under suboptimal conditions which can result in false absences in presence-only datasets. As a result, important habitats may be misclassified as unoccupied skewing conservation priorities. Additionally, the use of presence-only data often narrows the geographic and ecological scope of research.

Studies tend to focus on sites with previously confirmed presence, potentially excluding habitats where the species is present but undetected (Phillips 2006). This can lead to an incomplete understanding of the species' habitat preferences and limit the applicability of findings to broader landscape scales. For instance, habitat suitability models built on presence-only data may overemphasise well-surveyed areas while underrepresenting lesser-known but potentially important habitats (Kramer-Schadt 2013).

Temporal variation is another key concern. The spotless crake's activity and vocalisation vary seasonally and surveys conducted at suboptimal times may miss detection windows. Presence-only data which typically lack fine-scale temporal resolution fail to account for these fluctuations further limiting the accuracy of species distribution models SDMs.

Furthermore, the absence of absence data makes it difficult to distinguish between unsuitable habitat and undetected presence (Lobo 2010). This complicates our ability to determine the true drivers of species occurrence and constrains efforts to model responses to environmental change or predict future distributions particularly in the context of wetland degradation or climate variability.

More robust survey approaches that incorporate repeated measures occupancy modelling or detection/non-detection frameworks are increasingly recognised as necessary to address these limitations (MacKenzie 2002). These methods allow researchers to estimate detection probabilities and better account for imperfect detection ultimately improving the reliability of ecological inferences for cryptic species like the spotless crake.

In summary, while presence-only data remains a valuable starting point for understanding the distribution of elusive wetland species, their limitations must be acknowledged. To ensure effective conservation planning and habitat management for species like the spotless crake, future research should prioritise more comprehensive monitoring approaches that incorporate detection probabilities temporal variability and habitat heterogeneity.

Longterm Monitoring and Interannual Variability

Longterm monitoring ideally spanning multiple years would be instrumental in understanding the interannual variability in the vocalisation patterns of the spotless crake. By gathering data over an extended period, we can assess whether the seasonal patterns observed in vocal activity are consistent across years or whether they fluctuate in response to environmental changes, such as variations in climate wetland restoration efforts or other anthropogenic impacts. This approach would provide a clearer picture of how factors like temperature changes, rainfall or habitat alterations might influence the timing and intensity of crake vocalisations which could in turn affect their detectability and behaviour.

Conditions associated with non-crake sites

Such research would also be invaluable for predicting the potential impacts of future environmental shifts whether due to climate change, land use changes, or wetland management practices. Understanding how the spotless crake responds to long-term environmental changes would allow for more proactive and adaptive conservation strategies. In particular, this would enable conservationists and land managers to adjust monitoring and management efforts in response to trends that may affect crake populations ensuring that conservation strategies remain resilient and effective in safeguarding this cryptic species. Moreover, long-term data would help ensure that restoration efforts are optimally timed and tailored to support the species during critical periods of their lifecycle further improving the overall success of conservation interventions.

From the surveyed wetlands, no patterns emerged in sites without confirmed spotless crake presence however the following concepts arose:

- **Wetland size:** Non-crake sites tended to be smaller in area compared with crake sites, with the exception of one large wetland that did not have detections.
- **Shape and perimeter:** Univariate tests and logistic regression revealed no evidence that wetland shape distinguished between crake and non-crake sites. Further, wetlands with complex shapes or longer perimeters did not show consistent differences in occupancy.
- **Vegetation composition:** Vegetation categories showed low predictive power. Reedland was common in crake sites, however since reedland is found widely across sites, its utility as a predictor of absence is limited. Similarly, grassland and scrub habitats occurred in both site types, with *Coprosma-Olearia* scrub showing some negative trend but not at a significant level.
- **Connectivity:** Many non-crake sites had few or lacked nearby wetlands, but this was not a definitive feature, as several crake sites were also isolated. The absence of adjacent wetlands within 1-5 km does not reliably predict crake presence.

These findings suggest that landscape features cannot be used to reliably define where spotless crakes are absent. Although smaller wetlands and those lacking dense emergent vegetation may be less likely to support populations, crakes still occur in some small and isolated wetlands. This indicates that while habitat area, vegetation structure (especially reedland), and possibly connectivity may increase the likelihood of occupancy, absence cannot be confidently inferred from size, shape, or vegetation metrics alone. Monitoring and management should not overlook small or isolated wetlands, as these can contain crakes. Instead of assuming landscape-scale factors such as shape or connectivity are the sole determinants of suitability, conservation strategies should focus on maintaining or restoring fine-scale vegetation structure (particularly reedlands) across wetlands of varying sizes.

Implications for Regional Councils:

- **Do not discount small or isolated wetlands:** In our study several small and isolated wetlands also supported crakes. It should not be assumed that smaller wetlands are of lower ecological value—even small fragments may provide critical habitat or stepping stones for populations, particularly in fragmented landscapes.
- **Prioritise vegetation quality, not just wetland extent:** The presence of reedland emerged as a consistent positive association with crake presence. Focus should be placed on protecting and

restoring fine-scale vegetation structure within wetlands, especially dense emergent vegetation, as this seems to be a stronger determinant of suitability than overall shape or connectivity metrics.

- **Recognise uncertainty and imperfect detection:** Absence records cannot be interpreted as definitive due to the cryptic nature of spotless crakes. Caution should be taken when using survey data to inform consent processes, restoration priorities, or reporting against biodiversity targets. Decisions should explicitly acknowledge this uncertainty and incorporate repeat surveys or complementary methods (e.g., acoustic monitoring).
- **Broader management planning:** The findings suggest that effective management for cryptic wetland birds requires attentions to protecting and connecting larger wetland complexes, while also ensuring small, isolated sites retain high-quality vegetation that can support species like crakes.

The Impact of Detection Bias in Spotless Crake Survey Methods

Detection bias occurs when certain species or individuals are more likely to be detected due to factors unrelated to their actual abundance or presence (Hending 2025). It leads to skewed results in ecological studies and can be caused by several factors including:

1. Observer Bias: Differences in observer skills experience and attention
2. Methodological Bias: Variability in detectability based on the survey method used e.g. visual versus acoustic
3. Environmental Bias: Weather time of day or habitat conditions affecting species detectability
4. Temporal Bias: Species being more active or detectable at certain times of day or year
5. Spatial Bias: Uneven survey effort or site selection affecting results
6. Species-Specific Bias: Cryptic or elusive species being harder to detect
7. Equipment Bias: Tools used in surveys eg microphones camera traps affecting detection
8. Sampling Bias: Uneven sampling effort across habitats or areas leading to misrepresentation

In a survey, you would not restrict effort to known sites unless it was specifically to evaluate change. In a research study, restricting sampling to known sites may be entirely appropriate, depending on the question – but not in this case. By limiting the search for crakes to sites where their presence has already been confirmed, there is a significant risk of detection bias. This approach excludes sites where crakes may be present but not detected, potentially leading to an overestimation of detection success. It could also result in an incomplete understanding of the species habitat use as the factors influencing their presence at undetected sites are not considered. Consequently, the conclusions drawn about the species distribution and the effectiveness of monitoring methods may not accurately reflect the broader population or ecological conditions.

Enhancing Survey Methodologies and Conservation Strategies

In conclusion, further research into the drivers of seasonal vocal activity and the broader ecological factors influencing the spotless crakes behaviour is essential for refining our understanding of this elusive species. By exploring the intricate relationship between environmental variables such as temperature, habitat conditions, and breeding status we can identify the specific conditions that drive the crakes vocalisation patterns. These insights will enable us to finetune survey methodologies ensuring that monitoring efforts are both efficient and accurate and that we capture the full extent of the species activity across different seasons.

Expanding our knowledge of the crakes phenology, its seasonal patterns of activity, migration and breeding will allow for the development of more targeted survey protocols that align with the species natural rhythms. This could involve adjusting survey schedules to coincide with peak vocalisation periods or identifying the optimal times for detecting the species in specific habitats.

Furthermore, insights gained from studying the drivers of vocalisation can also inform broader conservation strategies. By recognising the key environmental and ecological factors that influence the crakes' presence and behaviour, conservationists can prioritise habitat restoration efforts in areas with the most potential for supporting crake populations. Moreover, understanding the seasonal and spatial patterns of crake activity will enable the creation of management strategies that address the species needs at critical times during its lifecycle such as during breeding or migration.

In the long term, this research will not only improve the monitoring and conservation of the spotless crake but will also contribute valuable knowledge to the management of other cryptic wetland species facing similar challenges. By applying this knowledge we can enhance our approach to conserving vulnerable species, ensuring that management efforts are both effective and adaptive to the changing environmental conditions, ultimately securing the long-term survival of these often-overlooked species in New Zealand's wetlands.

Enhancing Wetland Species Conservation Insights from Spotless Crake Research on Environmental Influences and Survey Methodology.

My research on the spotless crake is highly relevant to the conservation and management of other species, particularly those that are cryptic or elusive and depend on wetland ecosystems. Through my study, valuable insights into how environmental factors such as wind, speed, temperature, time of day, seasonality, light and cloud cover influence species detection and behaviour have been produced. These factors can similarly affect other wetland species including rare birds, amphibians, and invertebrates that exhibit challenges related to their cryptic nature or specific habitat requirements.

The vocalisation patterns of the spotless crake which are influenced by weather and environmental conditions provide a useful framework for understanding how other wetland species may respond to similar variables. My research provides a model for understanding how to conduct more effective and accurate monitoring of species with similar temporal or seasonal behaviour patterns.

This research highlights the importance of tailoring survey methods to the specific needs of each species, especially in the context of environmental and seasonal changes. Just as the response rate of the spotless crake to playback surveys varies with environmental conditions, other wetland species may show different behaviours depending on other factors. Understanding these variations helps refine survey techniques ensuring they are more sensitive to the ecological and behavioural needs of each species which leads to more reliable data collection.

The broader implications of my research also extend to habitat restoration and wetland conservation management. By understanding how environmental factors influence species activity and detection, this research will assist in the design of more effective conservation strategies. Wetland-dependent species rely on these ecosystems for critical life stages such as breeding foraging and migration. If surveys and conservation efforts are not designed to account for temporal seasonal and environmental factors, we risk missing critical windows for intervention. Restoration projects, for example, may be misdirected if species behavioural patterns are not fully understood in relation to fluctuating environmental conditions.

Lastly, the findings from my research can help shape broader wetland management practices. Wetland-dependent species require the maintenance of healthy environments to support their survival, and my study highlights that managing not just the physical characteristics of wetlands such as vegetation, water levels, and food availability but also the environmental conditions that affect species activity is essential. For instance, ensuring that wetlands are preserved or restored in ways that protect critical periods such as breeding or migration is crucial for supporting these species.

This study contributes new insights into the behaviour and habitat use of the spotless crake, a data-deficient and cryptic wetland species. By identifying key environmental and vegetation drivers of both vocal responsiveness and habitat suitability, it enhances the ability of researchers, land managers, and conservationists to detect and monitor this elusive bird. These findings will support more targeted conservation actions and improve outcomes for wetland biodiversity more broadly across Aotearoa and the wider Australasian region.

Chapter 5 - References

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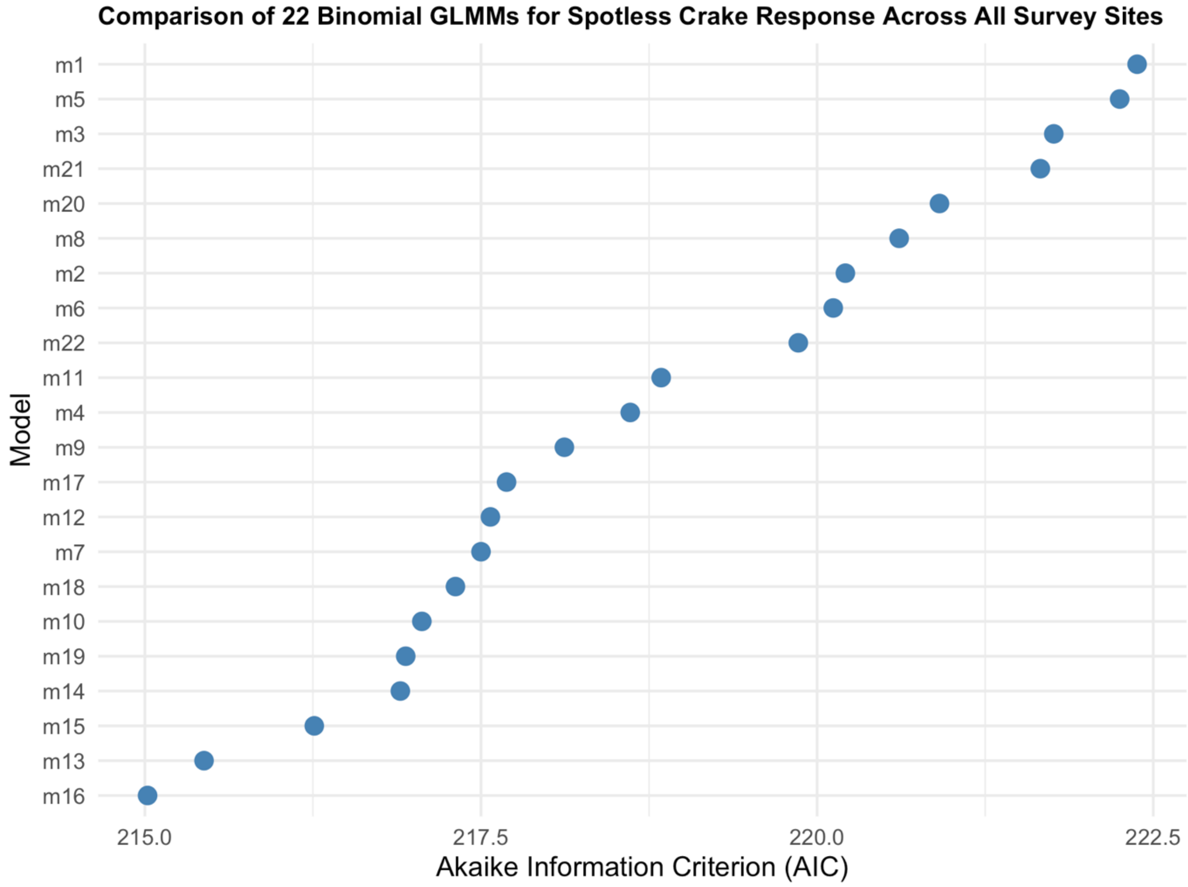
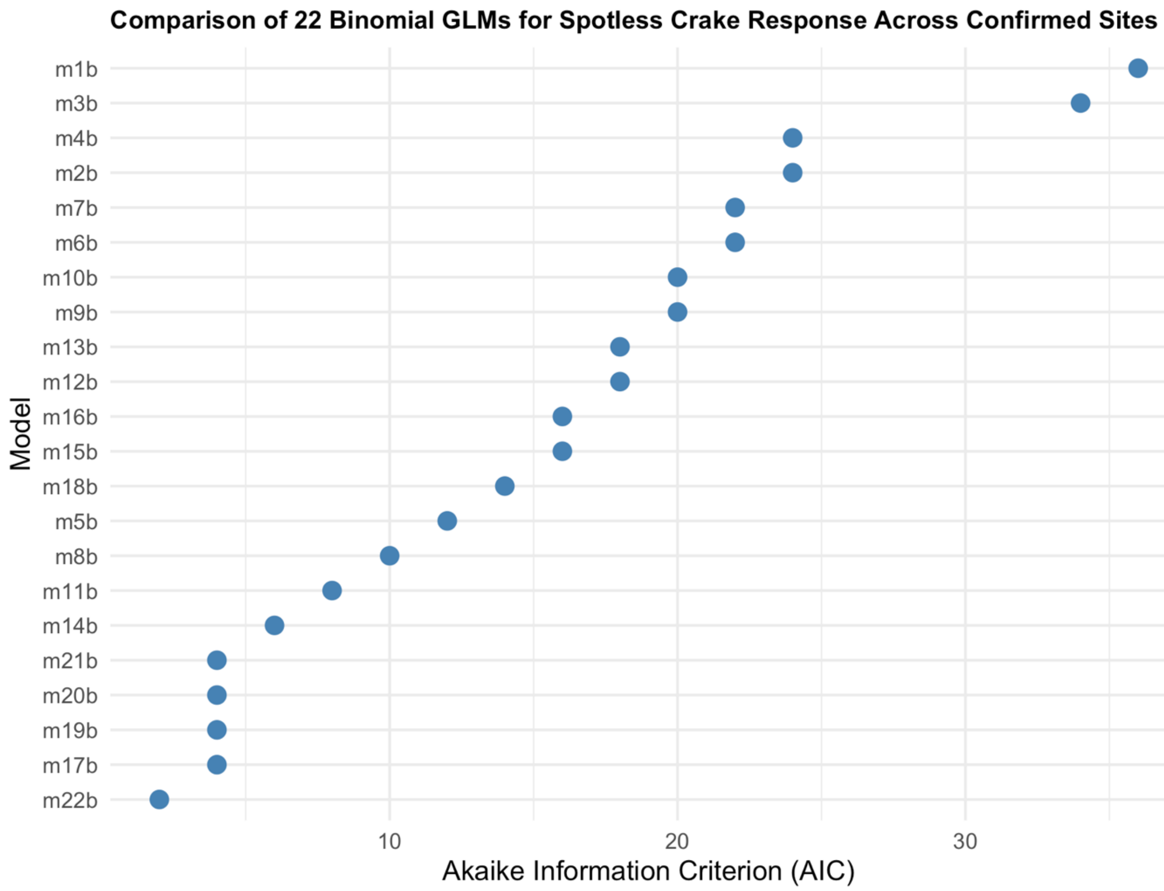
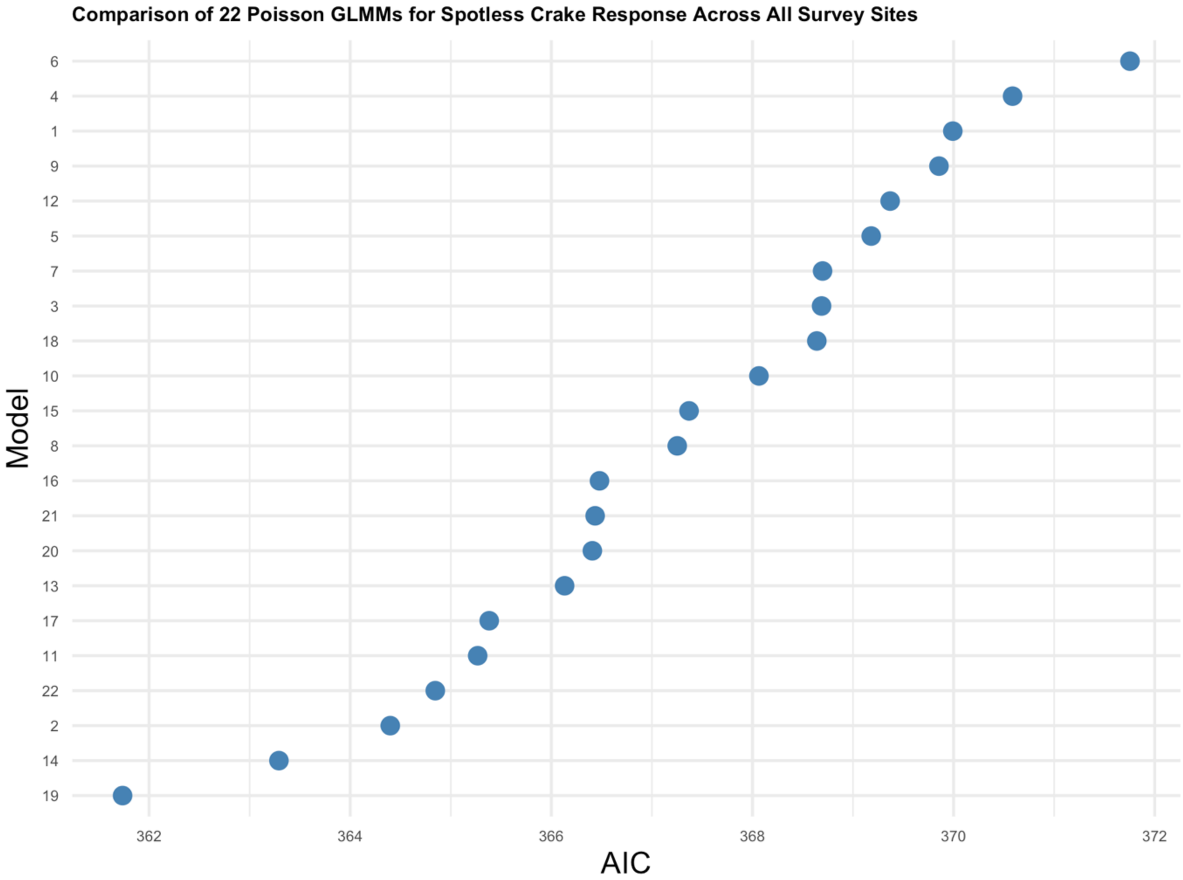
Chapter 6 – Appendix: AIC plots from candidate models.



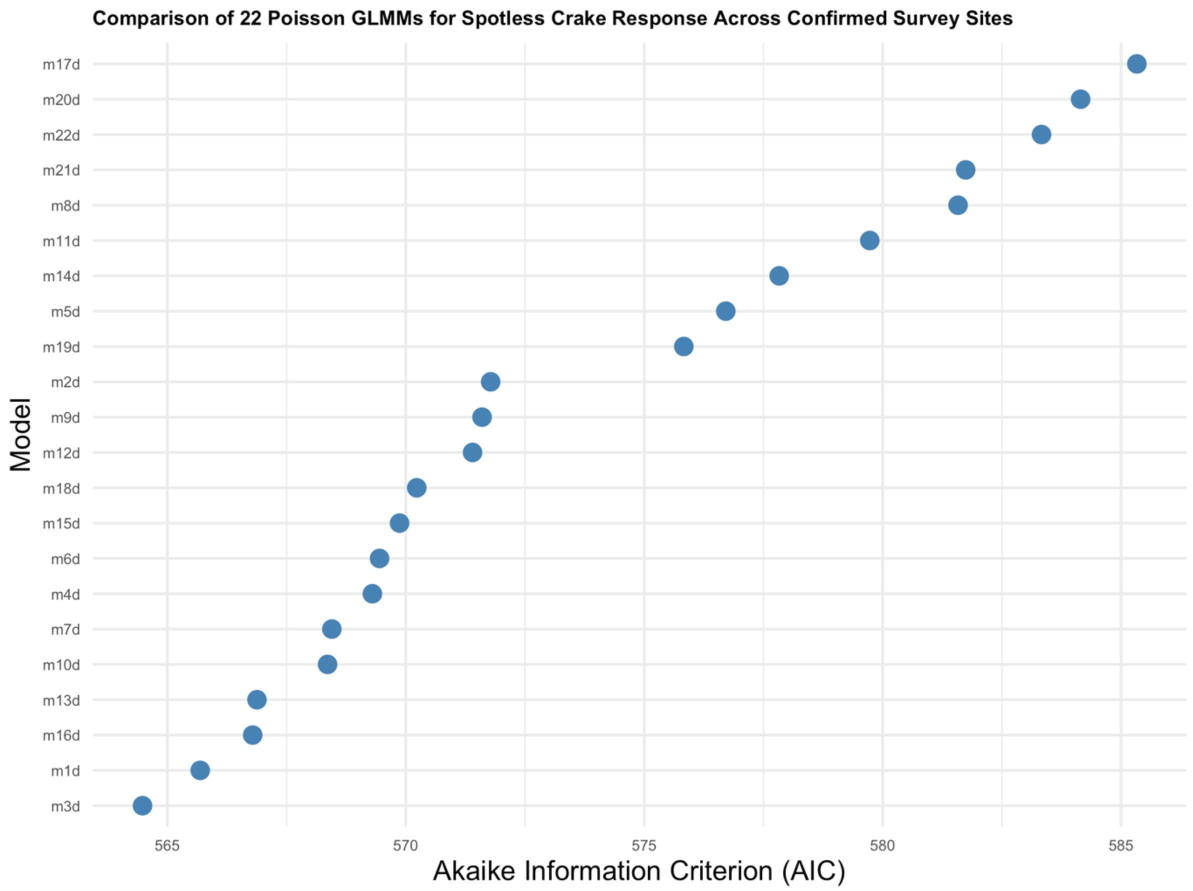
Appendix Figure 1. Comparison of 22 Binomial GLMMs for spotless crake response across all survey sites.



Appendix Figure 2. Comparison of 22 Binomial GLMs for spotless crake response across confirmed sites.



Appendix Figure 3. Comparison of 22 Poisson GLMMs for spotless crake response across all survey sites.



Appendix Figure 4. Comparison of 22 Poisson GLMMs for spotless crake response across confirmed sites.