Baseline monitoring of invasive predators on Arapaoa Island, Marlborough Sounds

September 2025

Sze-Wing Yiu, Markus Gronwald, Andrew Veale

Manaaki Whenua – Landcare Research, a group of the Bioeconomy Science Institute

Contract Report registration number: 2526-0035

Prepared for: Arapaoa Kiwi Trust

Reviewed by:

Graham Hickling
Principal Researcher - Wildlife Ecologist and Capability Leader
Manaaki Whenua – Landcare Research

Approved for release by:

Duane Peltzer
Portfolio Leader – Managing Invasive Species
Manaaki Whenua – Landcare Research

Contents

Summary

Project and client

Using strategic Science Investment Funding (SSIF), and in collaboration with the Arapaoa Kiwi Trust ('the Trust'), Manaaki Whenua – Landcare Research (MWLR)[1] conducted baseline monitoring of invasive predator populations on Arapaoa Island, Marlborough Sounds, between July 2024 and March 2025. The study was designed with a focus on invasive predators for the purpose of improving stoat and cat management strategies.

Objectives

- To obtain baseline camera-trap indices for the relative abundances of invasive predators, including feral cats, stoats, rodents, and hedgehogs, on Arapaoa Island.
- To examine the influence of season and vegetation type on the rat abundance indices.
- To assess the effect of season, vegetation type, prey (rodents), and competitors (cats/stoats) on the abundance indices of stoats and feral cats.
- To examine the relationship between kill-trapping rates and abundance indices of stoats.
- To compute and examine the effects of seasons and vegetation types on the population density (absolute abundance) and detection probability of feral cats.
- To determine the daily activity patterns of feral cats.

Methods

- We deployed 45 trail cameras on Arapaoa Island from July 2024 to March 2025, covering the four major vegetation types on the island (indigenous forest [forest], exotic forest [pine], mānuka and/or kānuka scrub [scrub], and fernland).
- We used camera detections to calculate indices of abundance for each invasive predator species, and regression analyses to assess the influence of season, vegetation type, and the relative abundance of prey and competitors on the indices.
- We estimated population density and detection probability of feral cats among seasons and vegetation types.
- We investigated the daily activity pattern of feral cats by assessing the frequency distribution of cat detections at different hours of the day and examining the peaks and troughs of their activities throughout the day.

[1] On 01 July 2025 Landcare Research New Zealand Ltd became the New Zealand Institute for Bioeconomy Science Ltd; Manaaki Whenua – Landcare Research operates as an internal group within this Institute, which is less formally known as the Bioeconomy Science Institute (BSI).]

Results

- Averaged across all seasons and vegetation types, abundance indices were 44.03/100 camera trap nights (CTNs) for rodents, 0.66/100 CTNs for stoats, 1.84/100 CTNs for feral cats, and 0.16/100 CTNs for hedgehogs.
- Rodent abundance indices did not differ among seasons, but they were significantly higher in scrub (mānuka/kānuka) compared to pine forest. Ship rats, kiore/Pacific rats and mice were grouped as 'rodents' because rodent species cannot be distinguished reliably from trail camera pictures.
- Stoat abundance indices were significantly higher in both spring and summer when compared to both winter and autumn and increased with the relative abundance of rodents but not influenced by the abundance indices of feral cats.
- We detected hedgehogs only during spring and summer (due to hibernation in colder months) and only within pine forests and scrub.
- The abundance index of feral cats was significantly higher in winter when compared to all other seasons; that was due to an increase in the detection probability of cats but not their population densities (absolute population sizes).
- At least 30 different individual cats were identified. We did not find any significant differences in cat population densities between seasons, and population densities were generally low across seasons (<0.3 cat/km^2). Detection probabilities were both higher in winter and autumn, when food is scarce, compared to both spring and summer.
- Cats were active throughout the day but had two peaks of activities, near dawn and dusk.

Discussion and conclusions

- While we observed differences in the abundance indices of stoats and rodents among seasons and/or vegetation types, it was not possible to conclude whether these differences resulted from changes in absolute population sizes, or in detection probabilities.
- The abundance indices of stoats were influenced by prey numbers (rodents), but there was no detectable effect of competitors (i.e. feral cats). This suggests a 'bottom-up' management strategy through controlling rats might be useful to support stoat control.
- Seasonal variations in the abundance indices of feral cats were due to changes in detection probabilities rather than population densities (absolute population size).
- Given that food availabilities are lower in winter and autumn, cats would have been more motivated to investigate the lures, and be more detectable. This suggests that cat control might be more effective (trapping success might be higher) during winter and autumn.
- Feral cat population densities are relatively low on Arapaoa Island, and detection probabilities higher when food is scarce in autumn and winter.

Recommendations

Camera monitoring should be continued on Arapaoa Island to monitor the outcomes of future predator management efforts.

- *Why?:* With the baseline information collected from this study, the Trust will be able to compare and monitor changes in invasive predators in response to management intervention.

Abundance indices should be interpreted with caution.

- *Why?:* Abundance indices are influenced by both absolute abundance and detection probabilities. Comparison of indices in the same vegetation type and season between different years will be more appropriate than comparing between vegetation types or seasons to draw implications on abundances without prior knowledge on detection probabilities. The Trust should therefore use the indices from this study as a baseline to compare against future indices.

We recommend establishing a new camera network having greater distances between cameras (1 km) to improve coverage of the island while ensuring major vegetation types are covered.

- This recommendation has now been adopted by the Trust.

It would be beneficial for wildlife managers and scientists to conduct further studies to better understand the interactions between feral cats and stoats

- *Why?:* To help avoid any unintended consequences of predator control.

Cat control efforts should be increased by the Trust during autumn and winter

- *Why?:* The current study found that cats are the most detectable and more likely to interact with control devices in these seasons.

1 Introduction

Domestic cats (*Felis catus*), regardless of whether they are feral, stray or owned, are listed by the International Union for the Conservation of Nature (IUCN) as one of the 100 worst invasive species (Lowe et al. 2000). In New Zealand (NZ), they are responsible for the extinction of at least nine native bird species, and they continue to threaten our native wildlife – including reptile species (Doherty et al. 2016; Gartrell et al. 2023).

While the social licence for the management of owned and stray cats is still lacking, support for feral cat management has been increasing (Farnworth et al. 2011; Kikillus et al. 2016). For example, strong public support for inclusion of cats emerged from the 2025 review of the Predator Free 2050 strategy, urging the Department of Conservation (DOC) to consider including feral cats on target species lists for management (DOC 2025a). There is also a Member's bill currently proposed by the Green Party to mandate microchipping and registering owned domestic cats (The Domestic Cat Microchipping Bill). This bill is a second attempt to improve cat management after a recommendation to Government by Parliament's Environment Select Committee to mandate registration and desexing of cats in response to a 2021 petition on this matter failed (Sharpe 2024).[2] Together with the increase in social engagement in discussing cat impacts, it is inevitable that cat management strategies will continue to develop and advance across the country.

Independent monitoring of predator abundances is essential for evaluating the progress and effectiveness of any predator management strategies. Predator abundances can be measured in two different ways.

1 *Relative abundance index* – an index of the relative population size that is presented as the number of independent detection events per unit effort.
2 *Population density* – an estimate of the absolute size (also called absolute abundance) of a population presented as the number of individuals per unit area (Hopkins & Kennedy 2004; O'Brien 2011).

Each of these methods have their own advantages and disadvantages.

Relative abundance indices are easier to measure, but they do not always correlate with the *absolute abundance* of the population because the indices are influenced by the detection probabilities of the animals (Martin-Garcia et al. 2022); a high relative abundance index could suggest either high number of individual animals or high detections of a small number of individuals. *Population density*, on the other hand, is challenging to estimate due to the complexities in modelling techniques and often requires the identification of individual animals (Twining et al. 2022).

Measuring *absolute abundance* allows understanding of the underlying reasons for population responses because most ecological processes, animal behaviour and the impacts of the invasive species on native species are density-dependent (Yokomizo et al. 2009; Norbury et al. 2015). For example, detecting and capturing an animal in a low-density population are more challenging than

[2] See https://bills.parliament.nz/v/1/54323726-e99a-445e-0739-08dd1d5bb970 and https://petitions.parliament.nz/d51b2df5-d789-405c-9cbf-8ef16c554973

that in a high-density population due to a reduction in competition for food, thus animals become less inclined to take risks and interact with any control or monitoring devices (Yiu et al. 2022; Davis et al. 2023). Furthermore, the development of density-impact functions, i.e. the relationship between predator population densities and impacts on native species, would enable determination of target thresholds (Norbury et al. 2015).

1.1 Project and client

In the 2024/25 financial year, MWLR was funded by the Strategic Science Investment Fund (SSIF) to estimate and predict cat population densities and detection probabilities in different environments across the country. This is fundamental for prioritising national cat management strategies.

Using this opportunity, we partnered with Arapaoa Kiwi Trust (hereafter 'the Trust') to undertake a baseline invasive predator monitoring study on Arapaoa Island, including an assessment of feral cat population densities.

The goal of the Trust is to eradicate stoat and reintroduce kiwi on Arapaoa Island. The Trust has established a trapping network that targets stoats (*Mustela erminea*) but has yet to establish an independent camera monitoring protocol. The Trust has also gained support from the local communities for cat control. We therefore aimed to collect baseline information of invasive predators to guide the Trust on their camera monitoring and future cat management protocols.

2 Objectives

- To obtain baseline camera-trap indices for the relative abundances of invasive predators, including feral cats, stoats, rodents and hedgehogs, on Arapaoa Island.
- To examine the influence of season and vegetation type on the rat abundance indices.
- To assess the effect of season, vegetation type, prey (rodents), and competitors (cats/stoats) on the abundance indices of stoats and feral cats.
- To examine the relationship between kill-trapping rates and abundance indices of stoats.
- To compute and examine the effects of seasons and vegetation types on the population density (absolute abundance) and detection probability of feral cats.
- To determine the daily activity patterns of feral cats.

3 Methods

3.1 Study area

Arapaoa Island (formerly Arapawa Island) is the second largest offshore island in the Marlborough Sounds. It spans an area of 75 km^2, and is located at the most eastern side of the sounds facing Cook Strait. Arapaoa has four distinctive seasons, a maritime climate, and an annual rainfall of over 1600 mm. The seasons are: spring – from September to November; summer - from December to February; autumn – from March to May; and winter – from June to August.

It is an inhabited island with both permanent and part-time residents and holiday visitors. The island was the largest whaling base in the area from early 18th century until the mid-19th century, and a large part of its native vegetation was cleared for logging, farming and pine forestry. Vegetation started to regenerate from 2000s, and the island is now a mix of indigenous broadleaved and/or podocarp forests, mānuka (*Leptospermum scoparium*) and/or kanuka (*Kunzea ericoides*) scrub, pine forests, and fernland (Figure 1). Only one farmland area remains at the central part of the island, occupying an area of approximately 5 km^2. The Department of Conservation has established three scenic reserves to protect the remnant distinctive Cook Strait forest communities consisting of kohekohe (*Didymocheton spectabilis*), tawa (*Beilschmiedia tawa*) and beech-podocarp-broadleaved species. The three reserves span a total of approximately 15km^2 on the island, with a partial fence built at some part of the northeastern coast to prevent goat and pig intrusions.

South Island kākā (*Nestor meridionalis meridionalis*), South Island robins / kakaruwai (*Petroica australis)* and tuatara (*Sphenodon punctatus*) used to inhabit Arapaoa, but they have now become locally extinct. The island still hosts numerous native bird species, e.g. New Zealand falcons/kārearea (*Falco novaeseelandiae*), bellbirds / korimako (*Anthornis melanura*), tomtit / miromiro (*Petroica macrocephala*) and weka (*Gallirallus australis*), and native geckos. The composition of invasive predators includes feral cats, hedgehogs (*Erinaceus europaeus*), stoats, ship rats (*Rattus rattus*), kiore / Pacific rats (*Rattus exulans*), and mice (*Mus musculus*), but not possums (*Trichosurus vulpecula*). There are also introduced ungulates on the island, including red deer *(Cervus elaphus*), pigs (*Sus scrofa*), goats (*Capra aegagrus hircus*), and feral sheep (*Ovis aries*). Arapaoa Island is separated from the mainland by the Tory Channel, which is narrow in width (averaging 1.1 km across), thus stoats and deer can possibly swim across the Channel.

The Arapaoa Kiwi Trust was formed in 2021 with the aim of eradicating stoats and reintroducing kiwi (*Apteryx* spp.) and has since established a trapping network of nearly 1,000 traps across the entire island (Figure 1). While there is currently no systematic cat suppression strategy, the Trust and numerous landowners have set and maintained 20 traps of different types that target cats across the island. Apart from the Trust, DOC has an ongoing goat control programme that aims to suppress the number of goats within the area of one of the scenic reserves.

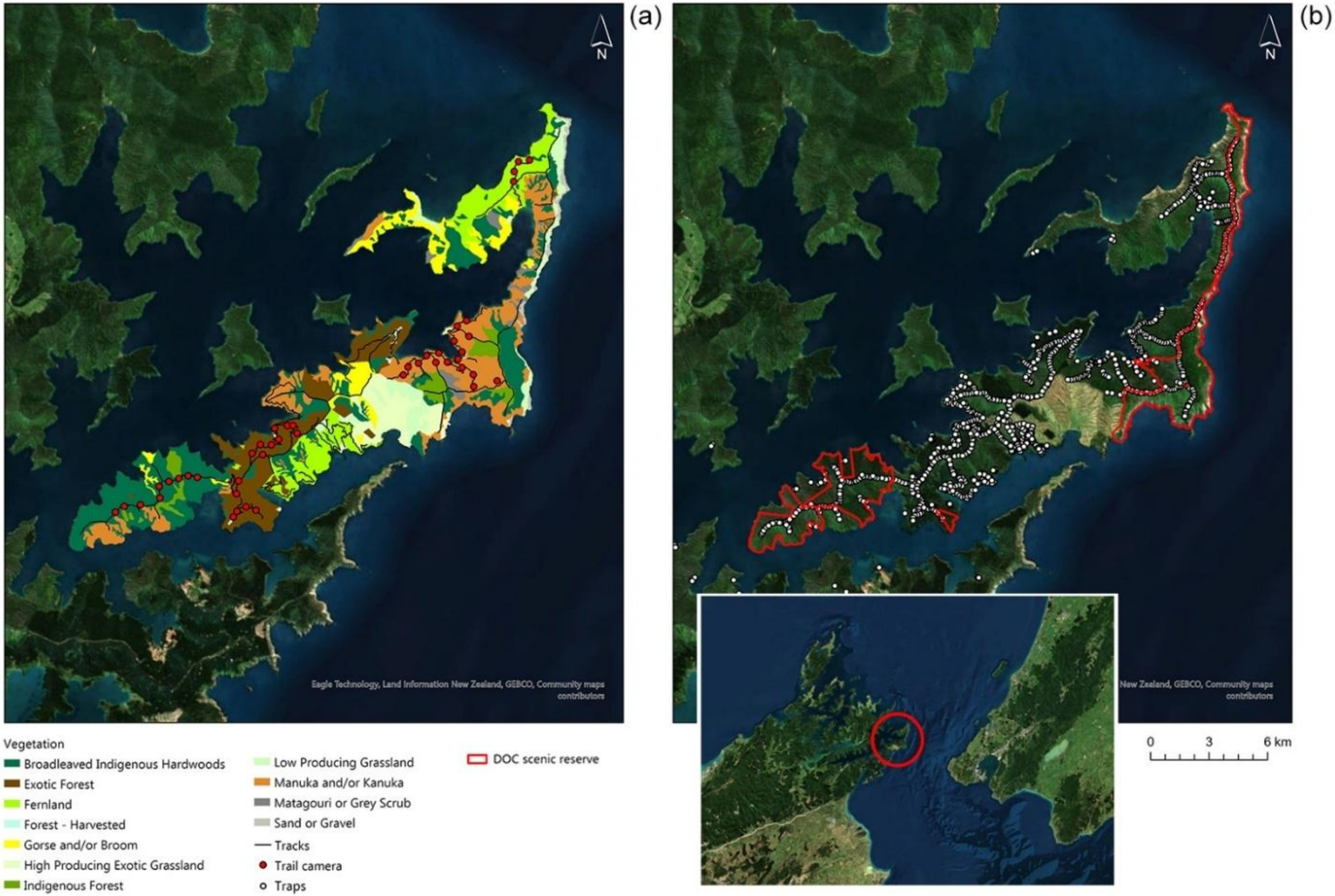

Figure 1. Arapaoa Island. (a) Vegetation types and the locations of camera (red solid circles). (b) Traps (white solid circles), and DOC scenic reserves (red boundaries) on Arapaoa Island. Inset map illustrates the location of the island (red circle) at Marlborough Sounds.

3.2 Data collection

In collaboration with the Arapaoa Kiwi Trust, we set up a total of 45 Browning trail cameras across the island from July 2024 to March 2025, covering all four seasons from winter to autumn. Camera models included 16 BTC-6HDPX Browning Dark Ops Pro X (with a single lens) and 29 Browning BTC-6DCL Dark Ops Pro (with dual lens). The cameras were distributed at 500 m intervals within the same vegetation type across the four main vegetation types: (1) indigenous forest (hereafter 'forest'); (2) pine forest (hereafter 'pine'); (3) manuka/kānuka (hereafter 'scrub'); (4) fernland. The 500 m intervals were selected to maximise captures of the same individual cats at multiple camera sites, which is necessary for estimating cat population density. Our camera sites were all located near existing tracks to avoid the hazards of accessing rugged terrain.

At each site, the camera was strapped to a tree at 25–30 cm above ground, i.e. approximately the shoulder height of a cat. A lure was placed 1.5–2 m away from the front of the camera. We trialled a tea infuser holding fish oil–soaked cotton balls as a lure, but they were not strong enough to withstand pig damage. The lures were therefore replaced with a piece of mahoe wood and the fish oil–soaked cotton balls were placed inside a hole drilled through the centre of the wood piece. The fish oil was replenished when needed during camera servicing. All cameras were set to picture mode, taking three pictures per trigger during both the day- and night-time, with no delay between triggers.

We also collated trapping data from the Trust's TrapNZ records (available at: https://trap.nz/project/4785139/info). Cat traps that were operated by the Trust were deactivated during the period of this study. The Trust also assisted us in collecting images and information on cats trapped in devices operated by private landowners for the use of this study.

3.3 Data analyses

3.3.1 Baseline abundance indices of predators

We identified and extracted pictures of our target species (cat, stoat, rodent, and hedgehog). Ship rats, kiore and mice were grouped as 'rodent' because rodent species cannot be distinguished reliably from trail camera pictures. Any pictures of the same species taken within the next 30 minutes were defined as the same encounter. It was not possible to estimate population densities of stoats, rodents and hedgehogs because they are not identifiable individually. We therefore calculated the relative abundance indices (hereafter 'abundance indices') of each species (including cats) separately for each season and vegetation type. Abundance indices were calculated as the number of encounters per 100 camera trap nights (CTNs), i.e. the total number of nights the cameras were active.

We then used linear regression analyses to assess the relative importance and effects of season and vegetation types on the abundance indices of rodents, and that of season, vegetation types, and the abundance indices of prey (rodents) and competitor (stoat/cat) on the abundance indices of stoats and cats. We compared the performance of a list of a priori models that include different combinations of the variables, with the best performing model suggesting the variables included in that model to be the most influential. Post-hoc tests were then conducted on the best model to compare all possible combinations between levels of each variable (e.g. winter vs summer and pine forest vs indigenous forest) to identify statistically significant differences.

To calculate trapping rates of stoats, we extracted trapping data collected from traps during the study that were within 2 km radius of the monitoring cameras. We allocated vegetation types to the traps based on their locations and calculated the trap nights for each trap. It was impossible to know exactly how many nights a trap was available to catch a stoat (a trap triggered would stay triggered and unavailable to trap until next trap servicing); therefore, trap nights were simply calculated as the number of nights the traps were in place – so the results should be interpreted with caution. Trapping rates of stoats were then calculated as the number of stoats trapped per 100 trap nights and compared with the relative abundance indices.

3.3.2 Absolute abundance (population density) and detection probability estimates for cats

As explained in Section 1, although relative abundance indices are the most common indices use in predator monitoring, they do not necessarily indicate the absolute population abundances (e.g. a low-density population with highly detectable animals might result in high indices). Therefore, we also estimated the absolute abundance of feral cats apart from relative abundance indices, which is possible because cats are identifiable individually.

To estimate cat population density, we identified each cat encounter to individuals if possible based on coat patterns and body features (e.g. missing body parts). Black or white cats with no distinctive features were defined as unmarked individuals. Pictures that were blurry or with partly visible cats were defined as unclear. We then compiled the capture-recapture histories of each identifiable individual and unmarked and unclear cats at each camera site.

Using this information and spatially explicit mark-resight analyses, we estimated the population density as the number of cats/km^2. Spatially explicit mark-resight analyses is a modelling technique that considers the movement of animals (by using the GPS locations of each detection) when estimating population density. The techniques allow for an understanding of the number of animals having their home range centre within the sampling area, i.e. the number of residents, by excluding animals that were transients only. We first fitted population model with season as a covariate, but the model had poor performance (high standard errors). We then fitted population models separately for each season, using vegetation type as covariate. While these seasonal models performed better than the first model that used season as covariate, they still did not perform well enough. We therefore removed vegetation types from these models (i.e. models were built separately for each season) which significantly improved model performances. We calculated the relative standard error for each density estimate (standard error/estimate x 100%) to assess the precision of the estimates. Each population model also estimated detection probability (g0), a probability ranging between 0 and 1 that shows how likely an animal would be detected when its home range centre is at the camera.

3.3.3 Daily activity patterns of cats

We examined the daily activity pattern of cats by applying a Kernel Density Estimator (KDE) to all cat encounters. KDE smooths the density distribution of cat encounters into a curve and shows the peaks and troughs of cat activities at different time of the day.

4 Results

4.1 Baseline abundance indices of predators

We detected rodents, stoats and cats during all four seasons and in all vegetation types. In contrast, hedgehogs were detected only during spring and only in pine and scrub (Figure 2, Figure 3; Appendix 1).

The abundance index (mean ± standard error [SE]) of rodents was 44.03 ± 9.92/100 CTNs averaged across seasons and vegetation. The best model for explaining rodent abundance indices included the interactive term between vegetation types and seasons, i.e. the effect of vegetation type differed with season. Rodents had significantly lower abundance indices in forest (7.63/100 ± 2.60 CTNs) and pine (21.65/100 ± 8.59 CTNs) compared to scrub (86.79 ± 14.00 CTNs), but only during the winter season (Figure 2b).

For stoats, the abundance index was 0.66/100 ± 0.20/100 CTNs averaged across seasons and vegetation. The best model included seasons and rodent abundance indices as variables, i.e. these two factors were more important than vegetation and cat abundance indices in affecting stoat abundance indices. The abundance index for stoats was significantly higher in spring (0.63 ± 0.62/100 CTNs) and summer (1.08 ± 0.16/100 CTNs) when compared to winter (0.19 ± 0.11/100 TNs) or autumn (0.25 ± 0.15/100 CTNs) (Figure 2a; Appendix 1,Table A1.1) and increased with the relative abundance of rodents (Figure 3).

The abundance index for cats was 1.84 ± 0.29/100 CTNs across seasons and vegetation. Our final model suggested that season was the most important factor influencing cat abundance indices, which were significantly higher in winter (4.21 ± 0.76/100 CTNs) when compared to all other seasons (<1.7/100 CTNs) (Figure 2a; Appendix 1, Table A1.1).

The abundance index for hedgehogs was 0.16 ± 0.02/100 CTNs across seasons and vegetation types. We did not conduct any statistical analyses on hedgehogs, but their abundance indices appeared to show a slight increase from spring (0.19 ± 0.10/100 CTNs) to summer (0.26 ± 0.15/100 CTNs) (Figure 2a; Appendix 1, Table A1.1) and were higher in scrub (0.39 ± 0.19/100 CTNs) than in pine (0.03 ± 0.03/100 CTNs) (Appendix 1, Table A1.2).

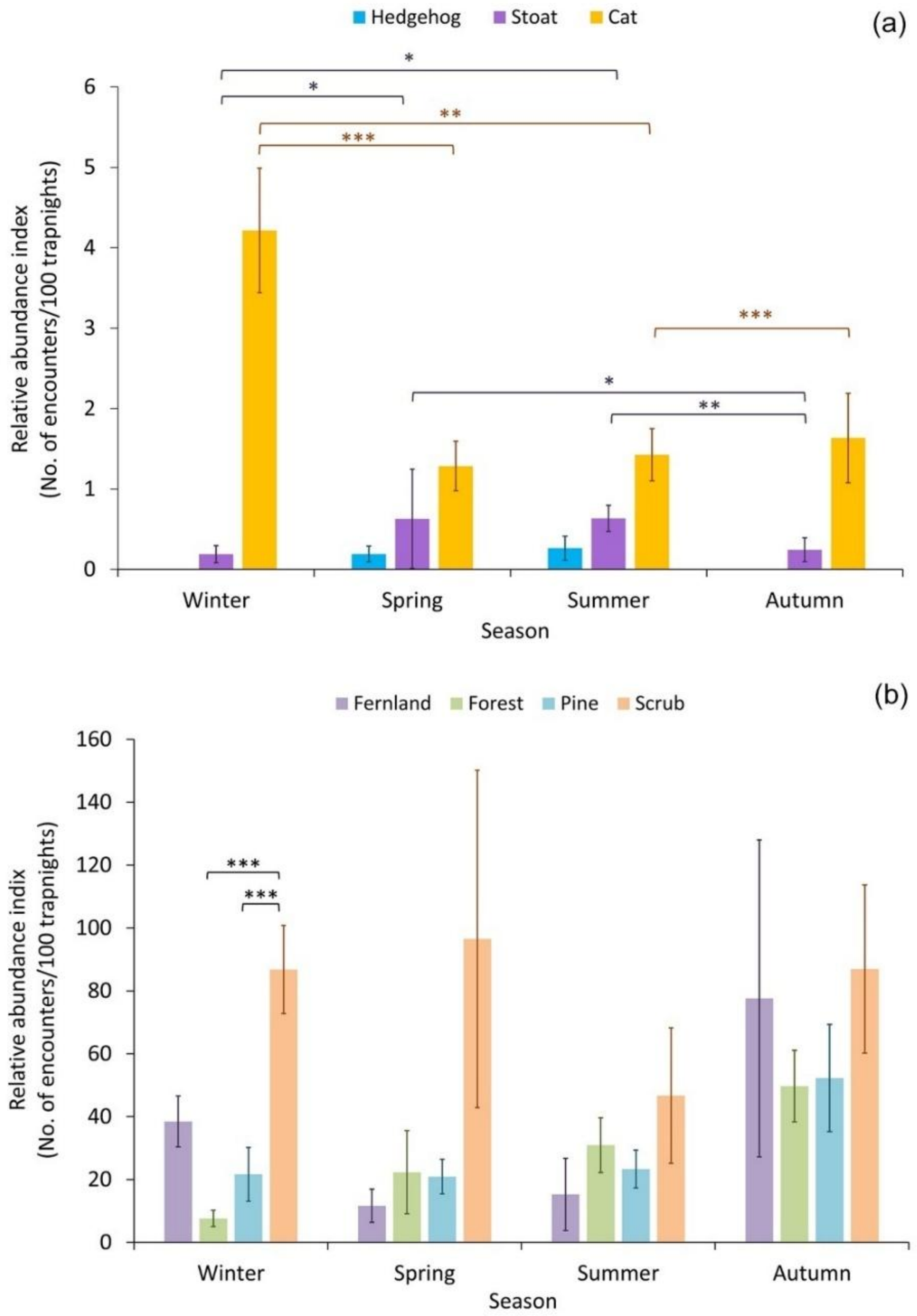

Figure 2. Abundance indices (mean ± SE) for different predators and seasons. (a) For hedgehogs, stoats, and feral cats in different seasons. (b) For 'rodents' (i.e. ship rats, kiore/Pacific rats, and mice) in different seasons and vegetation types. Horizontal braces above bars indicate statistically significant differences (* = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$).**

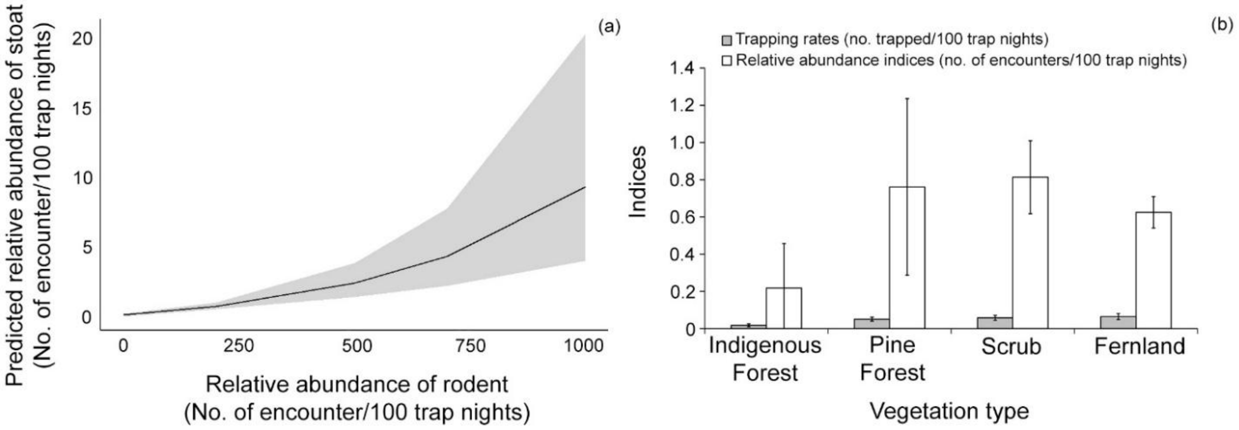

Figure 3. Trapping indices relating to stoats. (a) Relationship between relative abundance indices of rodents (ship rats, kiore, and mice) and stoats, grey shading shows confidence intervals. (b) Trapping rates and abundance indices of stoats in different vegetation types.

4.2 Trapping rates of stoats

Trapping rates for stoats was lowest in indigenous forests (0.02 stoats/100 trap nights) but similar among the other three vegetation types (0.05-0.06 stoats/100 trap nights). This aligns with the abundance indices for stoats that show similar trends of differences (Figure 3).

4.3 Absolute abundance (population density) and detection probability estimates for cats

Excluding the unmarked and unclear individuals, we identified a total of 30 different cats throughout the study. Among these 30 cats, the highest number of identifiable detections (encounters) for a single cat was 17, spanning from winter to summer. However, 18 cats were identified only once throughout the study. The identifiable cat detections resulted in a total of 118 encounters and the unmarked and unclear individuals a total of 70 encounters throughout the study.

We did not observe any significant effects of season on the population density and detection probability of cats. Population densities of cats were generally low and <0.3 cat/km^2 for all seasons (Figure 4a).

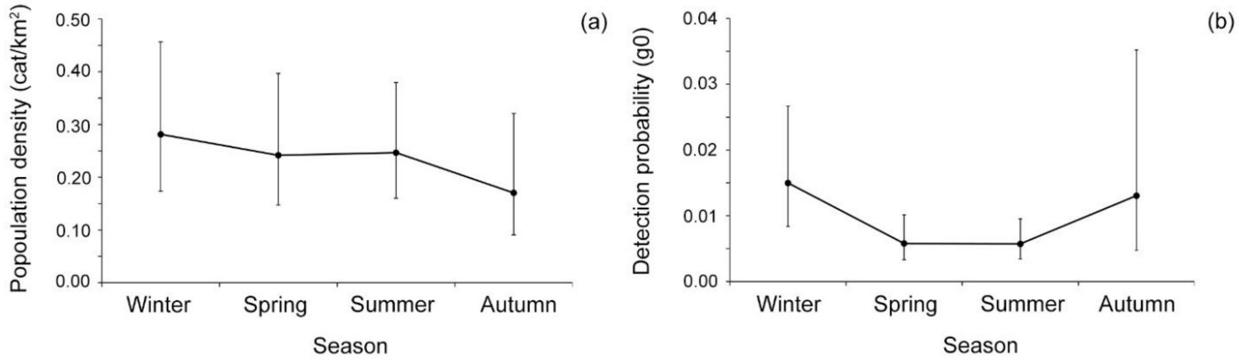

Figure 4. Estimates (estimates ± 95% confidence intervals [CI]) from spatially explicit mark-resight models. (a) Population densities. (b) Detection probabilities.

Relative standard errors for winter, spring and summer estimates were <26%, i.e. the estimates were reliable despite small uncertainty, but that for autumn was 33%, i.e. the precision was low and estimate uncertain. The detection probabilities of cats were higher in winter and autumn (>0.013) compared to spring and summer (<0.006) (Figure 4b).

4.4 Daily activity patterns of feral cats

Cats were active throughout the day, but their peak of activities was between sunset and sunrise, peaking at dawn and twilight (Figure 5).

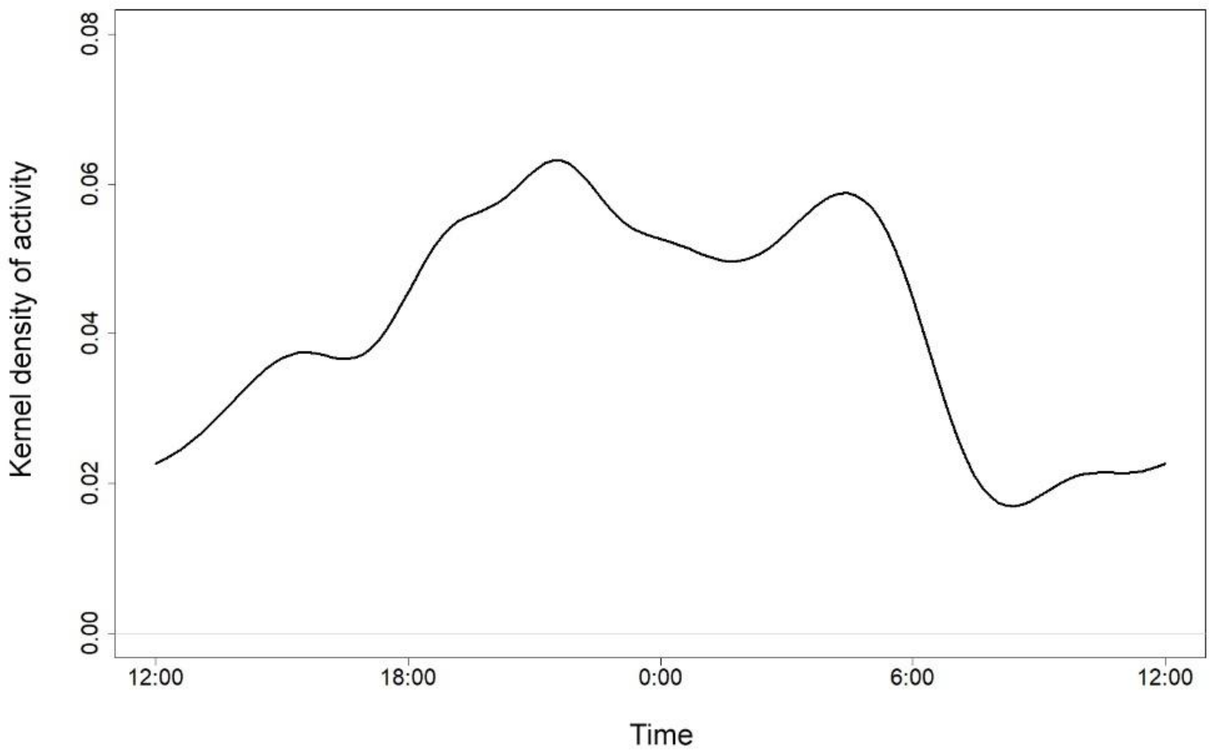

Figure 5. Kernel density estimation (KDE) for all feral cat encounters, showing the daily activity pattern of cats.

5 Discussion and conclusions

5.1 Rodents

In general, abundance indices of rodents did not vary significantly among seasons. However, abundance indices are influenced by both absolute population size and detection probabilities (see Section 1). Results on abundance indices therefore need to be interpreted with caution.

An absence of seasonal effects could suggest a stable absolute population size throughout the year, or that changes in the absolute population size were masked by changes in detection probabilities, e.g. rats are often low in population size but easier to detect during winter (Gronwald & Russell 2021). Similarly, we found the abundance indices of rodents were significantly higher in scrub compared to forests or pine during winter, which indicate either higher population size or detection probability, or both, in the former vegetation compared to the latter. The indices are therefore more suited for assessing between-year changes in the same vegetation type or season.

The abundance indices of rodents were high throughout the year and affected the abundance indices of stoats, with abundance indices of stoats increasing with that of the rodents. Since stoat abundance indices were driven by rodents, considering a 'bottom-up' control strategy for stoats by controlling rodents might be useful in the future (Norbury 2017; Travers et al. 2021). However, the success of such a strategy replies on the application of toxins island-wide, which might not be favoured by the residents.

5.2 Stoats

Apart from the abundance indices of rodents, the abundance indices of stoats were also influenced by seasons, peaking in spring and summer, which are breeding seasons for stoats (King & Forsyth 2021). As with rodents, the seasonal difference in stoat abundance indices might reflect an increase in their absolute population size due to recruitment, or it could also reflect higher detection probabilities as stoats roam widely for mating opportunities. Interestingly, the abundance indices of stoats on Arapaoa Island were much lower than on nearby D'Urville Island (>1.6 stoats/100 TNs), situated on the western side of Marlborough Sounds, despite of the fact that the abundance indices of rodents were much higher on Arapaoa than on D'Urville Island (Yiu et al. 2022). This suggests that there are other factors that regulate stoats apart from prey abundances.

One such factor could be the presence of competitors. Feral cats are in the same ecological guild as stoats; they thus compete for resources – and the suppression of either species might result in the increase in the other (Ruscoe et al. 2011; Garvey et al. 2022). In this study, we did not find any evidence of the two species influencing the abundance indices of each other. However, the evidence is not clear enough to conclude that competition or suppression did not occur. To assess the extent of competition between the two predators, a before-after control-impact experiment would need to be conducted (in which cats are removed from treatment sites to reveal the impacts on the abundance, detection probability and trappability of stoats).

The trapping rates of stoats were similar to the trend of their relative abundance indices: lowest in indigenous forests but similar among the other three vegetation types. This suggests that trapping was effective regardless of vegetation. Camera monitoring will be crucial in the long term to evaluate whether the trapping programme is successful in reducing stoat abundances over the years.

5.3 Cats

Season was the only factor influencing feral cat abundance indices, which were significantly higher during winter than all other seasons. However, we did not find any significant seasonal differences in the population densities, i.e. absolute population sizes, of the cats. Instead, the higher abundance index probably resulted from a higher detection probability of the animals during winter, as reflected in the higher g0 value in the population density model for winter. This, again, emphasises the disadvantage of using relative abundance indices to measure animal activities: changes in the indices might not result from changes in the absolute population sizes (O'Brien 2011; Martin-Garcia et al. 2022).

Feral cats had low population densities <0.3 cat/km^2 throughout the study in general. The detection probabilities for cats on Arapaoa Island were also low compared to other studies that used the same analytical technique (spatially explicit mark-resight modelling) (Vattiato et al. 2023). The low population density and detection probability contributed to the challenges of trapping cats as observed by the residents on the island. While generally low in values, detection probabilities of cats were higher in winter and autumn compared to spring and summer. This is not surprising given that food availabilities are lower in winter and autumn, therefore cats would have been more motivated to investigate the lures thus more detectable. This suggests that cat control might be more effective (trapping success would be higher) during winter and autumn when the cats are the most detectable. If population densities remain low in long-term, management protocol and tools that are more effective for low population densities might be required.

The Trust and the Arapaoa Island residents are currently using a mix of Timms, SA2, and live traps to target cats and face the challenge of minimising weka interference to the traps despite raising the traps. While standard weka-safe trapping protocol requires traps to be set at least 1 m above the ground (Thomson et al. 2001), the Trust might consider raising it higher (although that could also negatively affect trapping success). A study conducted at the Mōtū area in Gisborne had successfully reduced weka by-catch but was still capturing cats after raising their traps to a height of 1.3 m (Kemp 2013). In future, it might be worth designing experiments to compare the effectiveness of different weka-proof trap design in trapping cats. The Trust should also stay informed of the development of a new toxic bait (meat sausage containing sodium fluoroacetate [1080]) by DOC (DOC 2025b), should the island community become receptive of the application of toxins for predator control in the future.

6 Recommendations

Camera monitoring should be continued on Arapaoa Island to monitor the outcomes of future predator management efforts.

- *Why?:* With the baseline information collected from this study, the Trust will be able to compare and monitor changes in invasive predators in response to management intervention.

Abundance indices should be interpreted with caution.

- *Why?* Abundance indices are influenced by both absolute abundance and detection probabilities. Comparison of indices in the same vegetation type and season between different years will be more appropriate than comparing between vegetation types or seasons to draw implications on abundances without prior knowledge on detection probabilities. The Trust should therefore use the indices from this study as a baseline to compare against future indices.

We recommended a new camera network to the Trust, with greater distances between cameras (1 km) to improve coverage of the island while ensuring major vegetation types are covered.

- This recommendation has already been adopted by the Trust.

It would be beneficial for wildlife managers and scientists to conduct further studies to better understand the interactions between feral cats and stoats

- *Why?:* To help avoid any unintended consequences of predator control.

Cat control efforts could be increased by the Trust during autumn and winter

- *Why?:* This is when this study found cats are the most detectable and more likely to interact with control devices.

7 Acknowledgements

The project was funded by the MBIE Strategic Science Investment Fund (SSIF). We thank the Arapaoa Kiwi Trust for the collaboration and provision of logistic support required for the completion of the project. We especially thank Steve Dawson, for organising the equipment and managing camera servicing schedule and data collection, and Mark and Eian Denize for hosting us during our site visit. We thank the Arapaoa Island community for allowing access to their properties and their support for this study. We also thank Rachelle Binny (MWLR) for her advice on population modelling techniques.

8 References

Davis RA, Seddon PJ, Craig MD, Russell JC 2023. A review of methods for detecting rats at low densities, with implications for surveillance. Biological invasions 25(12): 3773-3791.

Department of Conservation (DOC) 2025a. Predator Free 2050: Strategy review discussion document. Wellington, Department of Conservation. 28 p.

Department of Conservation (DOC) 2025b. New bait to control feral cats shows promise. Stuff NZ, 14 May 2025. https://www.doc.govt.nz/news/media-releases/2025-media-releases/new-bait-to-control-feral-cats-shows-promise/ (accessed 31 Aug 2025).

Doherty TS, Glen AS, Nimmo DG, Ritchie EG, Dickman CR 2016. Invasive predators and global biodiversity loss. Proceedings of the National Academy of Sciences 113(40): 11261-11265.

Farnworth MJ, Campbell J, Adams NJ 2011. What's in a name? Perceptions of stray and feral cat welfare and control in Aotearoa, New Zealand. Journal of Applied Animal Welfare Science 14(1): 59-74.

Gartrell B, Jolly M, Tissink K, Argilla L, Esam F 2023. A retrospective study of native wild birds and reptiles admitted to three New Zealand wildlife hospitals due to predation by cats. New Zealand Veterinary Journal 71(2): 86-91.

Garvey PM, Glen AS, Clout MN, Nichols M, Pech RP 2022. Niche partitioning in a guild of invasive mammalian predators. Ecological Applications 32(4): e2566. https://doi.org/10.1002/eap.2566

Gronwald M, Russell JC 2021. Measuring rat relative abundance using camera traps and digital strike counters for Goodnature A24 self-resetting traps. New Zealand Journal of Ecology 45(1): 1-7.

Hopkins HL, Kennedy ML 2004. An assessment of indices of relative and absolute abundance for monitoring populations of small mammals. Wildlife Society Bulletin 32(4): 1289-1296.

Kemp F 2013. Predator control and the health and abundance of North Island weka—a report on the Motu region project. Wellington, Department of Conservation. 88 p.

Kikillus KH, Chambers GK, Farnworth MJ, Hare KM 2016. Research challenges and conservation implications for urban cat management in New Zealand. Pacific Conservation Biology 23(1): 15-24.

King C, Forsyth D 2021. The handbook of New Zealand mammals. 3rd edn. Clayton, South Victoria, CSIRO Publishing. 576 p.

Lowe S, Browne M, Boudjelas S, De Poorter M 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species databas. Auckland, Invasive Species Specialist Group (ISSG) of the SSg of the IUCN. 12 p.

Martin-Garcia S, Rodríguez-Recio M, Peragón I, Bueno I, Virgós E 2022. Comparing relative abundance models from different indices, a study case on the red fox. Ecological Indicators 137: 108778.
https://doi.org/10.1016/j.ecolind.2022.108778

Norbury G 2017. The case for 'bottom-up'pest management. New Zealand Journal of Ecology 41(2): 271-277.

Norbury GL, Pech RP, Byrom AE, Innes J 2015. Density-impact functions for terrestrial vertebrate pests and indigenous biota: guidelines for conservation managers. Biological Conservation 191: 409-420.

O'Brien TG 2011. Abundance, density and relative abundance: a conceptual framework. In: O'Connel AF, Nichols JD, Kanrath K eds. Camera traps in animal ecology: methods and analyses. Tokyo, Springer. Pp. 71-96.

Ruscoe WA, Ramsey DS, Pech RP, Sweetapple PJ, Yockney I, Barron MC, Perry M, Nugent G, Carran R, Warne R 2011. Unexpected consequences of control: competitive vs predator release in a four-species assemblage of invasive mammals. Ecology Letters 14(10): 1035-1042.

Sharpe M 2024. Compulsory microchipping and national register of cats proposed in bill. Stuff NZ, 18 December 2024. https://www.stuff.co.nz/nz-news/360471763/government-inaction-colossal-missed-opportunity-face-crisis-cats (accessed 31 Aug 2025).

Thomson C, Warburton B, Moran L 2001. Weka- and kiwi- safe possum trap sets. DOC Science Internal Series 24. Wellington, Department of Conservation. 16 p.

Travers T, Lea MA, Alderman R, Terauds A, Shaw J 2021. Bottom-up effect of eradications: the unintended consequences for top-order predators when eradicating invasive prey. Journal of Applied Ecology 58(4): 801-811.

Twining JP, McFarlane C, O'Meara D, O'Reilly C, Reyne M, Montgomery WI, Helyar S, Tosh DG, Augustine BC 2022. A comparison of density estimation methods for monitoring marked and unmarked animal populations. Ecosphere 13(10): e4165. https://doi.org/10.1002/ecs2.4165

Vattiato G, Binny RN, Davidson SJ, Byrom AE, Anderson DP, Plank MJ, Carpenter JK, James A 2023. Detectability of ten invasive mammal pests in New Zealand: a synthesis of spatial detection parameters. New Zealand Journal of Ecology 47(1): 3552. https://doi.org/10.20417/nzjecol.47.3552

Yiu SW, Gronwald M, Russell JC 2022. Reliable detection of low-density Pacific rats by using camera trapping. Wildlife Research 50(5): 398-411.

Yokomizo H, Possingham HP, Thomas MB, Buckley YM 2009. Managing the impact of invasive species: the value of knowing the density–impact curve. Ecological Applications 19(2): 376-386.

Appendix 1 – Abundance indices of predators

Table A1.1. Seasonal abundance indices of predators (number of encounters/100 trap nights), averaged across vegetation types

Species/Season	Winter	Spring	Summer	Autumn
Rodent	45.80	48.96	32.66	65.71
Stoat	0.19	0.63	0.63	0.25
Cat	4.21	1.28	1.43	1.63
Hedgehog	0.00	0.19	0.26	0.00

Table A1.2. Abundance indices of predators for different vegetation types (average across seasons)

Species/Vegetation	Fernland	Indigenous forest	Pine forest	Scrub
Rodent	20.51	26.09	25.44	75.47
Stoat	0.62	0.22	0.76	0.81
Cat	4.76	1.56	1.09	1.96
Hedgehog	0.00	0.00	0.03	0.39

Table A1.3. Abundance indices of predators for different vegetation types during different seasons

Vegetation/Season	Winter	Spring	Summer	Autumn
Hedgehog				
Fernland	0.00	0.00	0.00	0.00
Indigenous forest	0.00	0.00	0.00	0.00
Pine	0.00	0.07	0.00	0.00
Scrub	0.00	0.43	0.70	0.00
Rodent				
Fernland	38.46	11.68	15.27	77.61
Indigenous forest	7.63	22.30	30.93	49.72
Pine	21.65	20.95	23.35	52.31
Scrub	86.79	96.55	46.72	86.94
Stoat				
Fernland	0.00	0.73	0.28	1.82
Indigenous forest	0.00	0.32	0.29	0.00
Pine	0.18	0.91	1.02	0.26
Scrub	0.34	1.87	0.56	0.00
Cat				
Fernland	12.19	1.65	4.52	5.00
Indigenous forest	3.00	1.49	0.87	2.50
Pine	2.46	0.97	0.60	1.05
Scrub	4.31	1.35	1.86	0.50