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SHORT COMMUNICATION

Acoustic monitoring reveals widespread distribution of pekapeka across an isolated forest ecosanctuary, Sanctuary Mountain Maungatautari

Fiona N. Collie[1]*, Janelle M. Ward[2], Daniel Howie[2], Aaron Bertoia[1] and Joanne M. Monks[1]

[1]Te Tari Mātai Kararehe | Department of Zoology, Te Whare Wānanga o Ōtākou | University of Otago
[2]Maungatautari Ecological Island Trust | Sanctuary Mountain Maungatautari
*Author for correspondence (Email: fiona.collie@outlook.co.nz)

Abstract: Understanding population dynamics of endangered species in pest-free ecosanctuaries is essential to informing conservation planning, especially where populations are isolated in remnant forest within a matrix of unsuitable habitat. Little is known about whether fenced sanctuaries in Aotearoa | New Zealand are facilitating meaningful conservation of pekapeka (native bats). We conducted a bat survey at Sanctuary Mountain Maungatautari, Waikato, using acoustic monitoring at 20 sites to evaluate the presence and distribution of two species of endemic bats, the critically endangered long-tailed bat (*Chalinolobus tuberculatus*) and the lesser short-tailed bat (*Mystacina tuberculata*). We found no evidence of lesser short-tailed bats occurring within the sanctuary. We recorded 14 113 long-tailed bat passes across the 20 sites over 20 nights of good weather, suggesting widespread use of the area by foraging bats. Heat maps of passes revealed multiple hotspots of activity simultaneously, possibly indicating roosting locations, key foraging sites, or sites of social interaction. Increasing connectivity between the ecosanctuary and nearby forest via restoration planting and predator control may facilitate greater protection and genetic diversity of long-tailed bats.

Keywords: acoustic monitoring; bat; *Chalinolobus tuberculatus*; fenced sanctuary; *Mystacina tuberculata*; species reintroduction; survey

Introduction

Anthropogenic influence on the environment has been extensive and, in many cases, devastating (Frick et al. 2020). Habitat loss, fragmentation, and alteration of the landscape matrix are interdependent processes which have been responsible for high numbers of species extinctions globally (Herse et al. 2018). Following widespread habitat loss there comes inevitable fragmentation of ecosystems across a landscape, restricting dispersal and population connectivity (Fahrig 2003; Toth et al. 2015). Many species that had previously relied on the interconnected nature of a forest for foraging, shelter, and reproduction have become extirpated or experienced significant population decline following the removal of forest patches (Kouki et al. 2001). This can be due to genetic isolation, changes in the microclimate, and a depletion of available resources (Herse et al. 2018). Fragmentation has also been known to enhance the negative effects of competition or predation from introduced or invasive species (Dueñas et al. 2021; Henderson et al. 2021). Understanding the distribution and behaviour of species across their reduced range is essential for effective conservation planning and can inform strategies such as reintroductions (Jones et al. 2021).

Bats (Chiroptera) have been seriously impacted by the threats associated with anthropogenic habitat modification. They are an ecologically and taxonomically diverse group and account for roughly a fifth of mammalian diversity worldwide. Of the species assessed by the IUCN, roughly 80% require immediate conservation or research attention as a result of decreasing or unknown population trends (Frick et al. 2020). As keystone species in many environments, bats are essential to the healthy functioning of ecosystems by providing services such as pollination, insect control, and seed dispersal (Fenton & Simmons 2015).

Aotearoa is home two extant microbat species (pekapeka); the long-tailed bat (*Chalinolobus tuberculatus* Forster, 1844) which has the highest threat ranking in New Zealand: Threatened – Nationally Critical; and the lesser short-tailed bat (*Mystacina tuberculata* Gray, 1843) which is Threatened, Nationally Vulnerable. Both species were formerly widespread throughout the country (O'Donnell 2021a, 2021b). Pekapeka rely on large areas of mature native forest (Sedgeley & O'Donnell 1999; Sedgeley 2003, 2006) and have experienced significant range contractions since human arrival (O'Donnell et al. 2023). Declines within mature forest are primarily due to invasive mammalian predators, especially ship rats (*Rattus rattus*), cats (*Felis catus*), and stoats (*Mustela erminea*) (Pryde et al. 2005; O'Donnell et al. 2017) against which they have few defences (Smith et al. 2009). Intensive predator trapping and poisoning has improved the plight of some bat populations (Pryde et al. 2005; O'Donnell et al. 2017; Welch & Leppanen 2017), but many populations continue to decline

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despite intensive predator management, emphasising the need for self-sustaining populations of the species in predator-free areas (O'Donnell et al. 2023).

Sanctuary Mountain Maungatautari has been formally recognised as a reserve since 1912 but was not actively managed until 2006 when a predator-proof fence was completed, encircling nearly 3400 hectares of the mountain, making it Aotearoa's largest pest-proof fenced ecosanctuary. The successful eradication of all mammalian pest species except mice has facilitated the recovery and re-introduction of several native species (Innes et al. 2019). Maungatautari is in the range of both long-tailed bats (O'Donnell et al. 2023) and the central sub-species of short-tailed bats (*M. tuberculata rhyacobi*; Nationally Vulnerable) (Borkin & Parsons 2010). Having populations of both bat species in environments free from the pressures of introduced mammalian predator species is essential for their continued survival (Pryde et al. 2005; Borkin et al. 2023). Previous opportunistic acoustic surveys of the sanctuary in summer 2008 and winter 2020 indicated the presence of long-tailed bats (69 and 79 detections, respectively), not short-tailed bats; however, both surveys were ad hoc and limited in scope.

Our overarching objective was to contribute to an understanding of presence and distribution of pekapeka on Sanctuary Mountain Maungatautari, in accordance with the goals of the sanctuary's restoration plan (2019–2029; Innes et al. 2019). We did this via a comprehensive acoustic survey of the interior and perimeter of the sanctuary in summer 2022/23. Specifically, we addressed: (1) whether short-tailed bats are present at Maungatautari, (2) presence and distribution of long-tailed bats across the mountain, and (3) temporal activity patterns of long-tailed bats at Maungatautari in summer. Collectively, our data enable recommendations on management and monitoring for pekapeka in and around the sanctuary.

Methods

Data collection

Maungatautari is a native forest-covered andesitic volcanic cone (797 m a.s.l.) surrounded by extensive farmland in the Waipā district, Waikato. The maunga (mountain) supports a highly diverse old-growth native forest, with an abundance of the large cavity-filled trees suitable for bat roosts (Innes et al. 2019). Due to the extensive coverage of suitable broadleaf-podocarp forest, it is feasible that bats could be identified at a range of sites within the sanctuary, warranting a mountain-wide survey.

We used acoustic monitoring to determine species presence, utilising 21 omnidirectional frequency compression automatic bat monitors (ABMs; AR4 model, Department of Conservation, Wellington), as they are the best-practice tool for acoustic detection of both long- and short-tailed bats (Smith et al. 2020). These recorders were placed at predetermined locations across the mountain (internal; Fig. 1) and on the sanctuary perimeter (perimeter; Fig. 1). Key considerations for site selection included site accessibility, spatial coverage of the area, and re-sampling sites used in previous surveys (Table 1; Fig. 1). The mean distance between neighbouring recorder sites was 1216.7 m (min = 699 m, max = 2224.5 m). All ABMs were pre-set to start monitoring c. 1 hour before sunset and

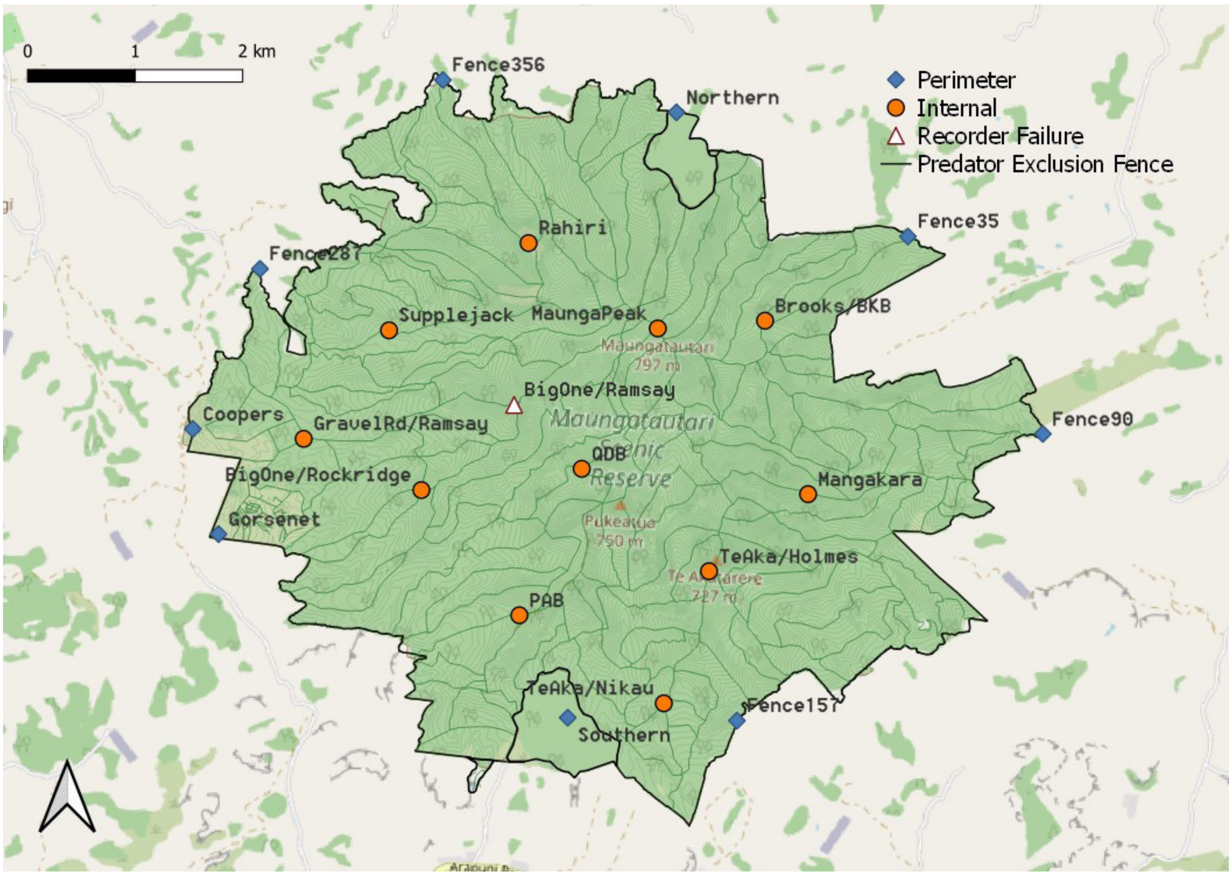

Figure 1. The 21 sampling points across Maungatautari Ecosanctuary (11 internal, orange; 9 perimeter, blue; 1 failed, white).

stop recording at c. 1 hour after sunrise. Times for sunrise and sunset at the time of the study were approximately 6.30 a.m. and 7:30 p.m., respectively. The ABMs were suspended approximately 2–3 m above the ground, in an area with a clearing (where possible) within each site. The sites included a range of peripheral and more enclosed areas, which improves the probability of detection for both species as it accommodates for both aerial (long-tailed bat) and closed-space (short-tailed bat) foraging strategies (O'Donnell et al. 2006). Each ABM was left in place for at least 14 fine-weather nights (max. 28 total nights between 19 December 2022–10 January 2023) before collection. One recorder was excluded from analysis as it fell from its tree after the first night. Surveying was carried out in the summer, when both species are most conspicuous (O'Donnell et al. 2006). The mean temperature recorded in the area for the evenings included in the study was 21°C, rainfall was only recorded on 28/12/2022 and 06/01/2023 (22 and 11.2 mm per 24 h respectively).

Data processing and analysis

We used BatSearch3.1 software (developed by DOC; 2016) in accordance with protocols described by Lloyd 2017) to process the data gathered. This software allows for species identification and pass counts by analysing spectrograms of their calls. While both bat species use echolocation, differences in call sequences and frequencies allow for relatively accurate discrimination between species (i.e. short-tailed bats c. 28 kHz and long-tailed bats c. 40 kHz) but not between individuals. We quantified the number of bat passes (spectrograms containing identified call sequences) for each species, per recorder, per night. Before analysis, any nights with high weather interference (from wind or rain; Lloyd 2017) were removed from the study, because such interference compromises the ability to identify bat echolocations within a spectrogram.

We used QGIS (version 3.28.4-Firenze) to produce heat maps as graphical representations of detection data. Heat maps were colour coded to reflect the mean number of bat passes for every night the ABM was active at each site. Further heat maps were produced to reflect mean pass rate during 3-hour timeframes around dusk and dawn (one hour before, one during, and one after). This enabled us to identify sites with the highest acoustic activity and suggest potential roost site locations or other site usage such as feeding or social interaction.

We ran a generalised additive mixed model (GAMM) with a negative binomial distribution using the package mgcv (Wood 2017) to investigate the relationship between bat passes and time of night. The model contained counts of bat passes recorded on the bat detectors as the response variable, with time of day (coded as the number of hours past dusk) as a smoothed predictor variable. Site was included as a random effect. We used additive models as we expected the relationship between bat passes and time of day to be non-linear, as bats are commonly active at dawn and dusk (Griffiths 2007).

Results

No short-tailed bat passes were recorded at any of the sites used throughout the entirety of this survey, therefore henceforth 'bat passes' will refer only to long-tailed bats. In contrast, every ABM successfully recorded long-tailed bats, even the

Table 1. Number of long-tailed bat passes (total and mean/night) recorded at each site. Bold text indicates sites with minimum and maximum mean passes per night. *Excluding bad weather nights **Recorder fell on ground night one.

Site	# of nights recording*	# of long-tail passes	Mean passes/ night
BigOne/Rockridge	15	132	8.8
Brooks/BKB	17	295	17.4
Coopers	12	306	25.5
Fence157	17	890	52.4
Fence287	17	915	53.8
Fence35	18	1994	110.8
Fence356	17	1868	109.9
Fence90	18	247	13.7
Gorsenet	11	156	14.2
GravelRd/Ramsay	15	268	17.9
Mangakara	17	424	24.9
Maunga Peak	**18**	**92**	**5.1**
Northern	17	677	39.8
PAB	8	203	25.4
QDB	**18**	**2398**	**133.2**
Rahiri	4	151	37.8
Southern	17	1512	88.9
Supplejack	18	420	23.3
TeAkatarere/Holmes	17	709	41.7
TeAkatarere/Nikau	17	456	26.8
BigOne/Ramsay**	1	4	4

failed unit. We recorded a total of 14 113 bat passes over 20 good weather nights with 20 recorders (excluding the failed recorder; Table 1). The minimum number of passes recorded at a single site over the duration of the study was 92 (Maunga Peak) and the maximum was 2392 (QDB) (Table 1). Observed differences between mean internal ($n = 11$) and perimeter ($n = 9$) passes per night were not significant (57 vs. 33, $\chi^2 = 2.426$, df = 1, p = 0.119).

The site with the highest mean passes per night was QDB with 133 (2398 passes/18 nights), followed by Fence 35 (110.8; 1994 passes/18 nights) and Fence 356 (109.9; 1868 passes/17 nights) (Fig. 2). The lowest mean passes per night were at Maunga Peak (5.1; 92 passes/18 nights), BigOne/Rockridge (8.8; 132 passes/15 nights), and Fence 90 (13.7; 247 passes/18 nights) (Fig. 2). In the c. 3 hours around dusk (between 7–9:59 p.m.) the highest mean bat passes were found at the Southern enclosure, followed by Fence 287, Rahiri, and QDB (Fig. 3). Around dawn (between 4–6:30 a.m.) the centres for activity were different, with the highest mean bat passes found at QDB, followed by Fence 356, and Fence 35 (Fig. 4). In the 30 minutes following the first recorded pass, most nights were showing between one to three major areas with high acoustic activity (hotspots) located at different points across the maunga, generally with one in the southern/central region, one in the north-west, and one in the north-east (Fig. 5).

We found a significant bimodal relationship between bat passes and time of day, where bat passes peaked at 9 p.m., followed by a relatively steady period, before increasing again towards 5 a.m. ($\chi^2(7.94) = 79.9$, $p < 0.001$; Fig. 6).

Discussion

Long-tailed bats

The mean number of long-tailed bat detections in our survey, when compared to other studies (e.g. O'Donnell 2000; Borkin & Parsons 2009), indicates frequent activity within the sanctuary, suggesting that an important population of critically endangered long-tailed bats are using the sanctuary at Maungatautari. Because all 21 of the recorders used in this study picked up at least one long-tailed bat pass, it is likely that bats utilise a signification portion of the sanctuary and its perimeter. In the areas with less activity this use may simply be as fly-bys or short periods of feeding. However, areas with high activity such as QDB in the centre of the sanctuary and the southern enclosure site, along with perimeter sites Fence 35 and Fence 356, are potentially within the roosting range of at least one colony of bats (Fig. 2). Alternatively, these areas could be utilised for other activities such as feeding or social interaction. The high level of activity seen in these areas around dusk and dawn may also be indicative of nearby roosting sites, as these times are when bats would be leaving and returning to their roost trees (Figs. 3 & 4). Long-tailed bats are known to use pathways, edges, or natural clearings such as waterways to travel throughout forests (Borkin & Parsons, 2009; Dekrout et al. 2014; Rockell et al. 2017). Although one interior site had high levels of activity (QDB), this site is close to a 1–2 m wide walking track, providing open space for bats to travel. Other interior sites had many fewer detections, suggesting that the open areas of tracks and the perimeter are well utilised by long-tailed bats at Maungatautari.

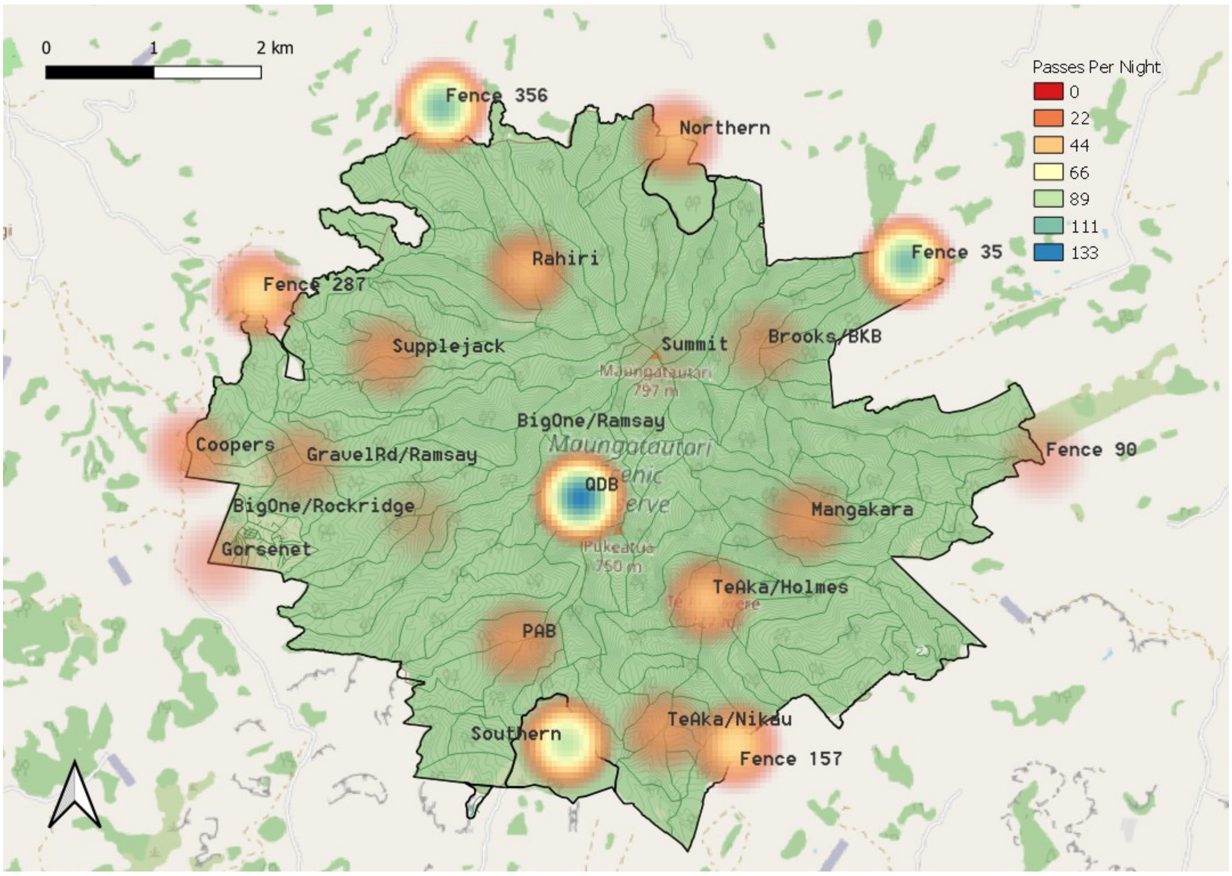

Figure 2. Mean long-tailed bat passes per night, per recorder scaled from red (lowest) to blue (highest).

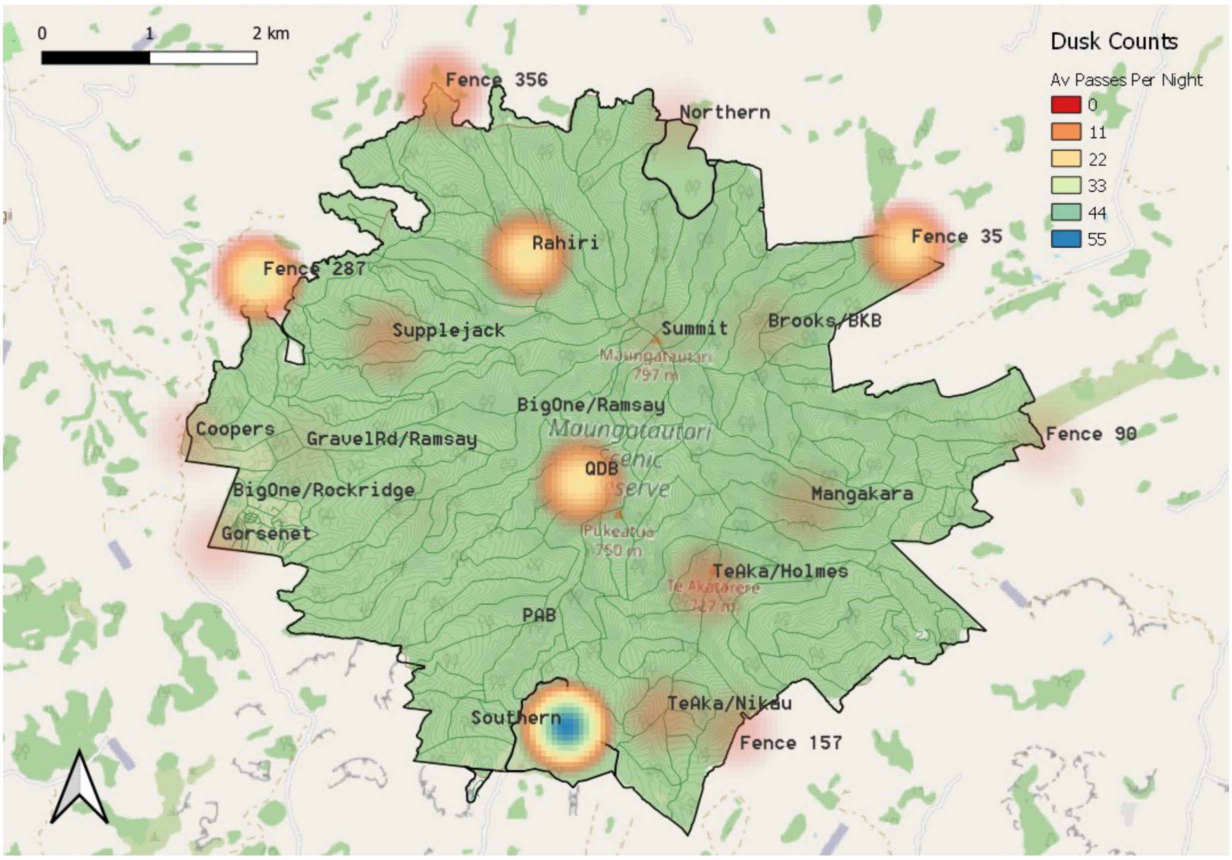

Figure 3. Mean long-tailed bat passes in the c. 3 hours around dusk (between 7–9:59 p.m.) per night, per recorder scaled from red (lowest) to blue (highest).

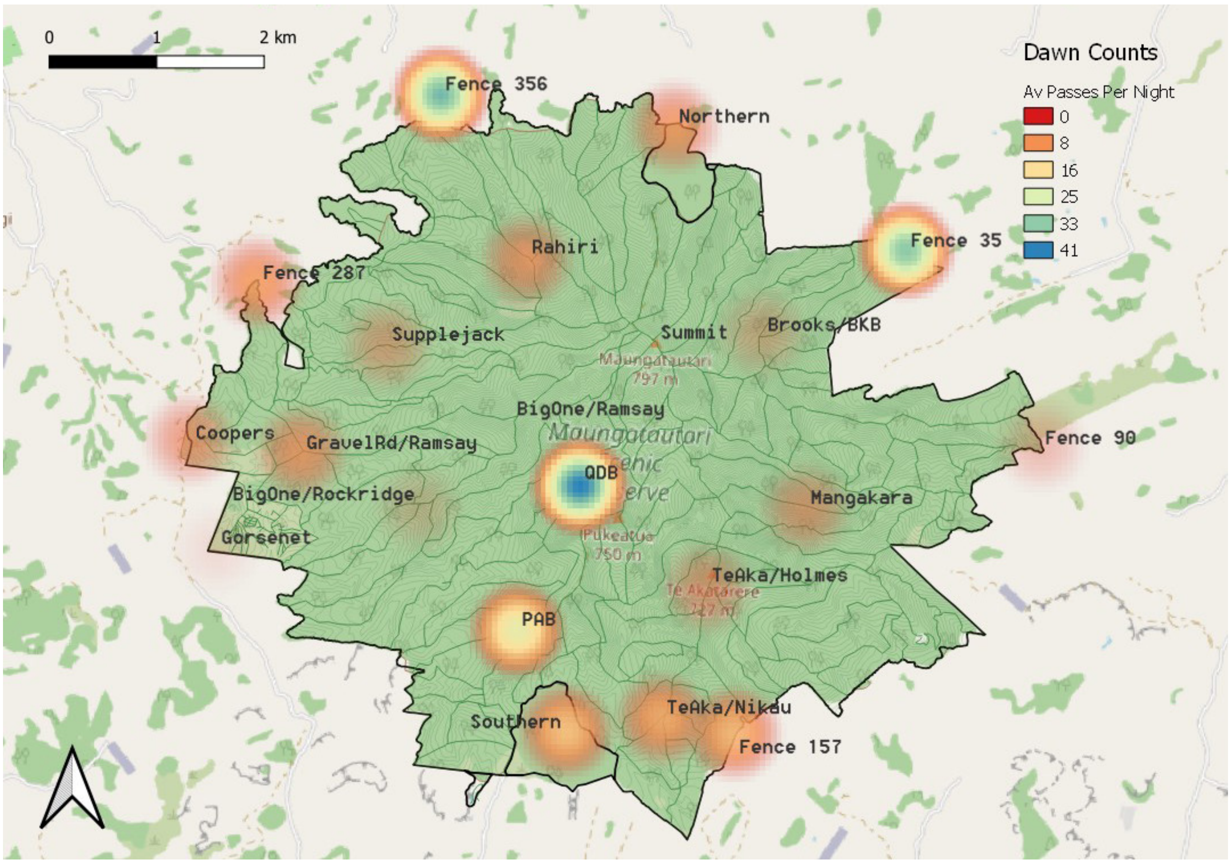

Figure 4. Mean long-tailed bat passes in the c. 3 hours around dawn (between 4–6:30 a.m.) per night, per recorder scaled from red (lowest) to blue (highest).

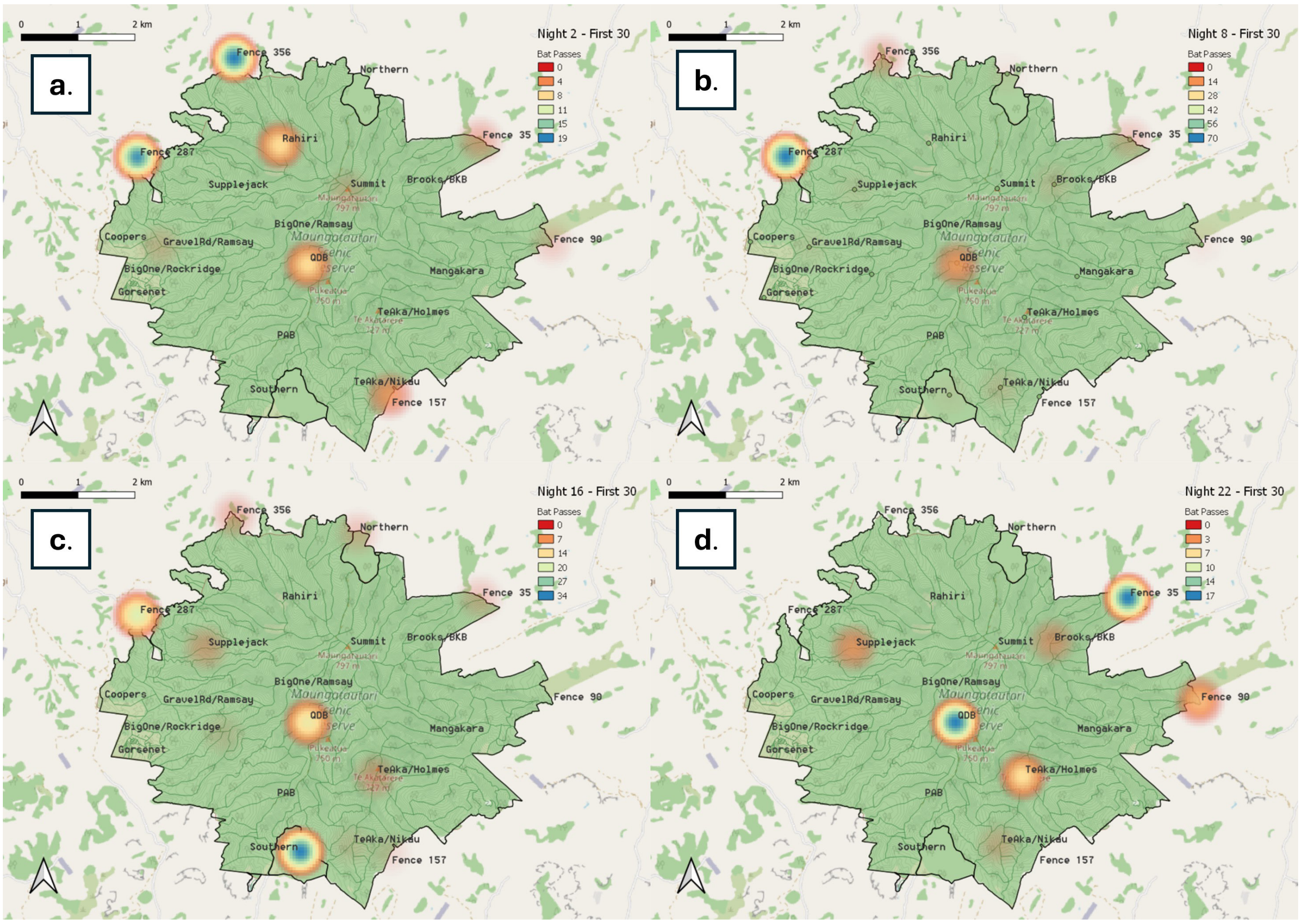

Figure 5: Long-tailed bat passes within the first 30 minutes of four individual nights (a = night 2, b = night 8, c = night 16, and d = night 22). Hot spots (brighter/larger) indicate the sites with the most activity.

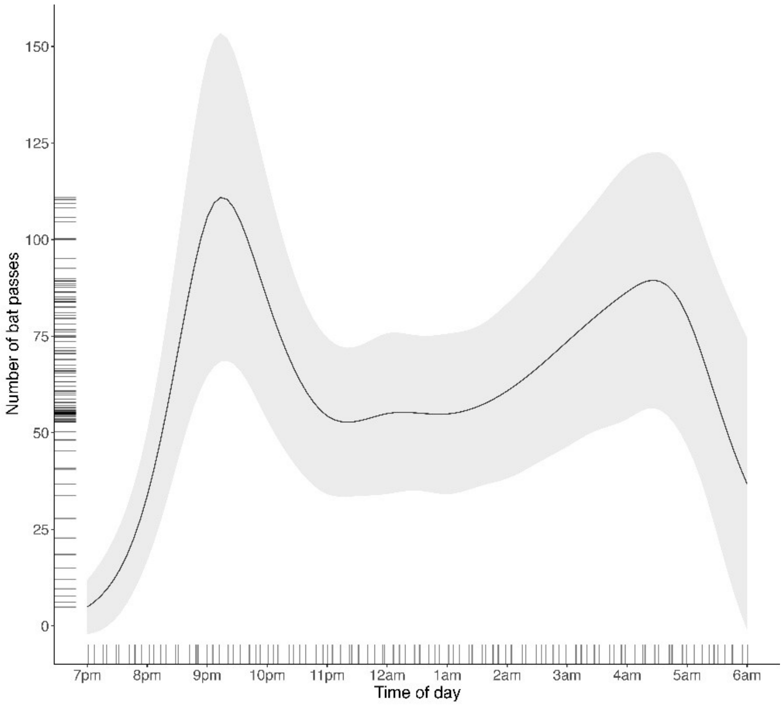

Figure 6. The relationship between bat passes at the 20 sampling points across Sanctuary Mountain Maungatautari and time of day ($p < 0.001$). The shaded grey area represents a 95% confidence interval and the rug on the x and y axis represents the distribution of the bat passes.

There were multiple points of activity during the half hour following the first pass each night, and passes were seen at recorders on opposite sides of the mountain within minutes of one another (Fig. 5). This could potentially indicate that there are multiple long-tailed bat roosts across the maunga. Because long-tailed bats are capable of flying up to 60 kmph, it is possible the same individual bats were recorded at multiple locations across the mountain within this short time period. However, given that bat foraging behaviour involves swooping along treelines rather than straight, direct flights, it seems more likely that the patterns seen indicate multiple individuals than repeated, multiple detections of the same individuals. Capturing and tracking individual bats with radio telemetry would be necessary to confirm roost site locations, and these 'hotspots' may indicate good points to target bats for capture.

Emergence times of long-tailed bats vary across Aotearoa (Feng 2022). Significant peaks in bat activity immediately after dusk and, to a lesser extent, before dawn at Maungatautari are consistent with knowledge of general bat activity patterns (Griffiths 2007). These results are useful in planning efficient long-term monitoring of the population via acoustic recorders.

Short-tailed bats

Despite significant survey effort, we found no evidence of short-tailed bats within or along the periphery of Sanctuary Mountain Maungatautari. This adds comprehensive survey information to previous ad hoc surveys using ABMs and hand-held bat detectors where short-tailed bats were undetected. Because of the coverage of the survey through the interior and along the perimeter, we would have expected to detect short-tailed bats had they been present, although it is possible that small numbers in specific locations may have been missed in the large sanctuary area of 3400 ha. Short-tailed and long-tailed bats coexist at many sites and are thought to have minimal interspecific competition due to differing foraging ecology, so it is unlikely that the presence of long-tailed bats is the cause of this absence (O'Donnell et al. 2006).

The closest known population of short-tailed bats to Sanctuary Mountain Maungatautari is at Pureora Forest (c. 70 km south of the sanctuary). Although bats are known to travel great distances, O'Donnell et al. (2006) suggest that short-tailed bats are less adapted to highly fragmented and cleared forest habitats than long-tailed bats are. It is therefore assumed that they have not recolonised the maunga following local extirpation caused by invasive mammalian predators due to poor habitat continuity between the sanctuary and other remnant populations. Natural recolonisation is likely to be safer for bats than assisted translocations, as there has never yet been a successful long-term translocation of any bat species globally (Ruffell et al. 2009), partially due to effective homing abilities following displacement (Guilbert et al. 2007; Baerwald et al. 2021). The establishment of vegetation corridors to link remnant forest sites may facilitate natural recolonisation. Any corridors established, however, would have strong edge effects and, consequently, would require effective predator control.

Our mountain-wide acoustic survey suggests that lesser short-tailed bats are absent from Sanctuary Mountain Maungatautari. In contrast, the mountain is utilised by long-tailed bats, and thus represents an important safe haven for this Nationally Critical species. To obtain a more accurate understanding of the number and size of colonies the mountain hosts it would be necessary to radio-track individual bats to undertake roost counts at maternity roosts during the breeding season. In the short term we recommend more extensive monitoring and surveying at this site. Following this we recommend habitat restoration coupled with intensive predator control in the surrounding land outside the fence and between Maungatautari and Pureora to provide better protection for the long-tailed bats venturing outside the sanctuary, and to potentially enable short-tailed bats to naturally recolonise the mountain in the future.

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Additional information and declarations

Author contributions: FC, JW, DH and JM conceived and designed the study. FC and DH carried out the majority of data collection. FC wrote the manuscript with contributions from AB and JM for analysis. All authors contributed to editorial efforts.

Data and code availability: Data and code are available on request from the corresponding author.

Ethics: Ethics permission was not required for this project.

Conflicts of interest: The authors declare no conflicts of interest.

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