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RESEARCH

Testing the effectiveness of a novel approach to measure a large roosting congregation in a wetland ecosystem.

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Abstract: The National Wetland Trust constructed a 1400 m long pest exclusion fence around a 11 hectare site at Rotopiko and all mammals except mice have been eradicated from inside the fenced area. Since the completion of the pest proof fence, the number of roosting birds has increased dramatically. By removing mammalian pests, an unexpected sanctuary has been created for communal roosting birds such as starlings (*Sturnus vulgaris*) and sparrows (*Passer domesticus*). There is growing concern about the large amounts of bird faeces produced each day and the associated nutrient load particularly as the pest fence encircles a low nutrient peat lake. In this study two methods were developed for estimating the relative abundance of the large roosting congregation, based on (1) gridded plates for gathering guano and (2) the acoustic energy of the roost cacophony. The results showed that these methods were suitable for measuring the characteristics of the roosting community at multiple scales. For example, large variance in the abundance of roosting and diurnal birds, and minor changes in the roosting community according to seasonal fluctuations. The methods could support the management of the issue through being applied to assess and quantify the relative efficacy of preventive or control methods deployed to reduce the number of exotic birds. The findings of this study are site specific; however, the guano plates and sound recorders could be implemented to estimate large bird numbers at other sites facing a roosting bird problem.

Keywords: abundance estimation, communal birds, competitive release, population assessment, colony management, roosting impacts

Introduction

New Zealand's early separation from Gondwanaland, approximately 80 million years ago, and the long period of isolation that followed, might mean that New Zealand's biota lack mechanisms to defend themselves against terrestrial mammalian predators (Monks et al. 2019). Prey-predator relationships and competition for resources between introduced and endemic species are key issues associated with biodiversity decline. For example, rats and possums are generalist species with a more aggressive and competitive nature that helps them to appropriate niches exploited by the more sensitive New Zealand biota (Adams et al. 2013).

The susceptibility of New Zealand's biota to alien species has driven the development of various strategies to control and manage introduced mammals. For example, offshore islands have been used for biological conservation in New Zealand since the late 1800s, when Little Barrier Island was selected as a sanctuary for birds (Pryde 1997). Miskelly & Powlesland (2013) revealed that 55 species of New Zealand birds have been translocated to sanctuaries where their populations are able to survive and grow without the threat of predators. The conservation success observed in the offshore islands resulted in this approach being implemented to the New Zealand mainland.

The mainland ecosanctuary model has gradually increased since the completion of Warrenheip in Waikato and Zealandia in Wellington in 1999, as the principle of conservation efforts targeted to restore ecosystems instead of single species continues to develop. This concept involves designing and constructing a fence that acts as a barrier for mammalian pests around an area of interest, which is then intensively managed to eradicate all the pests inside. The National Wetland Trust (NWT) has constructed a 1400 m pest exclusion fence around a 11 hectare site comprising a c. 10 000 year old, 1 hectare peat lake with swampy margins, a c. 400 year old kahikatea forest stand, and restoration plantings of various ages. All mammals except mice have been eradicated from inside the fenced area. The (NWT) is an organisation that aims to protect wetland ecosystems and their functions, and to increase public awareness of wetland values, including ecosystem services. Rotopiko is a community-led restoration project frequently used by local schools and youth groups to introduce young New Zealanders to conservation and nature. For the local hapu, Ngāti Apakura, Rotopiko is an important cultural site that has provided Māori with food, medicines, and traditional construction materials for hundreds of years. Taonga species

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such as eels are an important food source for Māori and are still present at the site. The pest exclusion fence was completed in 2013; however, since the completion of the pest proof fence, the number of roosting and diurnal exotic birds has increased dramatically. Roosting birds are the individuals that arrive at the site before sunset and leave after sunrise the following morning. Communal roosting birds spend the night as a large group to assist with survival strategies such as body temperature regulation and predation avoidance (Mazumdar et al. 2017; Manzoor et al. 2021). Diurnal birds are the individuals present at the site during the daytime. The eradication of mammalian pests has created an unexpected sanctuary for communal roosting birds such as starlings (*Sturnus vulgaris*) and sparrows (*Passer domesticus*) which now form a roosting community comprising in the hundreds of thousands. Every night approximately an hour before sunset, birds arrive at the site to roost in the pest-free sanctuary. Challenges like this could potentially arise throughout New Zealand as the Predator Free 2050 goal approaches.

There is increasing concern about the large amount of bird faeces produced each day at Rotopiko and the associated high concentration of nutrients, such as nitrogen and phosphorous. Fujita and Koike (2007), from their study of nutrient inputs to different habitats via birds, demonstrated that forest areas with high roosting populations had elevated nutrient concentrations. The phosphorous input from birds accounted for 12.4% of the phosphorous input to a non-roosting forest and 52.9% to a roosting forest, while nitrogen inputs were estimated at 5.2% in a non-roosting forest and 27% in a roosting forest. Peat lakes like Rotopiko have unique characteristics, such as low nutrient levels and naturally acidic waters, and provide habitat for animals and plants suited to those conditions (Clarkson & Peters 2012). The community of roosting birds at Rotopiko must be controlled to prevent potential negative effects, such as long-term effects on the chemical and physical characteristics and biota of the site, decline in low nutrient-requiring species, and an increase in nutrient-demanding species. In addition, the roosting birds compromise the visual impacts and public health and safety. In recent years, the NWT has implemented several options to deter the birds such as noise disturbance and laser lights. While the NWT initially relied on twice yearly five-minute bird counts and visual assessments of guano plates to monitor the effects, the sheer number of birds precluded reliable results, and highlighted the need for a monitoring system that was capable of accurately estimating changes in the roosting bird community.

Different methods are currently used to monitor birds in New Zealand. Some methods, such as distance sampling, aim to estimate the absolute density while others, such as five minute bird counts, aim to achieve indexes of relative abundance (Greene 2012). Both distance sampling and five minute bird counts, rely on the detection of individual birds, which is difficult to achieve at Rotopiko because of the magnitude of the issue. Photography techniques are commonly used to count birds in large numbers, aerial photographs are often used for sea birds as they can detect individual birds without any impediments. (Cantos et al. 1999) developed a more sophisticated method to directly count large congregations of birds using remote techniques via thermal infra-red sensors; this method was also used to count sea birds. In a forest environment, photography counts are less useful for birds roosting within the vegetation, as visuals are obstructed by the canopy (Moore & Powlesland 2012). Historical attempts have been made to develop robust methods to count large roosting congregations. Symonds (1961) developed a direct monitoring system based on the entry flying behaviour of starlings to the roost. The dimensions (depth, width, length, time) of the entering bird stream was used to estimate the roosting population. This method could be hampered by the development time, as it took eight years to develop because of variation in the birds entering the roosting site and observer bias. Stewart (1973) developed an indirect technique based on estimating the number of roosting birds according to the droppings produced from individuals and the entire roost. The method involved deploying paper sheets and sticks of different dimensions to accumulate droppings in the area of interest. Then, dried samples were weighed to calculate an estimate of the roosting population. While these approaches have proved useful, there is a need for a reliable method to estimate large roosting populations in wooded areas.

Restoration projects such as Rotopiko fit into current central government policies that aim to restore, and avoid the loss of, wetland areas. The National Policy Statement for Freshwater Management 2020 included several new policies to guide local governments towards more efficient management of wetlands. This wetland restoration also fits with the purpose of the Te Ture Whaimana o Te Awa o Waikato (Vision and Strategy for the Waikato River) part of the Waikato Tainui River settlement, which is has a high priority in the proposed Healthy Rivers Plan developed by Waikato Regional Council. The aim of this project therefore was to develop a monitoring tool for estimating the relative abundance of the roosting population and to assess the efficacy of future control measures at Rotopiko. The system was based on droppings that accumulated on a gridded plate without the time limitation for drying samples reported in the method of Stewart (1973). The method was supplemented and validated using sound recorders that measured the acoustic energy emitted by the roost.

Methods

Study site

Rotopiko is located approximately 15 km south-east of Hamilton, New Zealand (Fig. 1). The current complex of three peat lakes has evolved from a larger peat lake formed in the last glaciation (Green & Lowe 1985). The pest proof fence was constructed around what is currently known as the East Lake. The fenced area includes a drain receiving outflow from adjacent land and surrounding catchment discharging to the lake. The East Lake has unique native aquatic plant assemblages (*Potamogeton ochreatus, Potamogeton cheesemanii*) and native fish, such as long-fin eels (*Anguilla dieffenbachia*) and common bully (*Gobiomorphus cotidianus*) (Wu et al. 2013; Waikato Regional Council 2021).

Study design

During the initial site visit in July 2020, roosting locations were identified from evidence of bird droppings on the ground. The roosting locations were delimited, and the projected coordinates were recorded using a Garmin eTrex-20. Geographic information system (GIS) technology was then used to create a grid map of the monitoring stations in the parts of the reserve disturbed by roosting birds (Fig. 2). The monitoring stations were selected remotely, to randomise the direction of monitoring lines and create a systematic sampling approach that avoided selecting stations that only contained

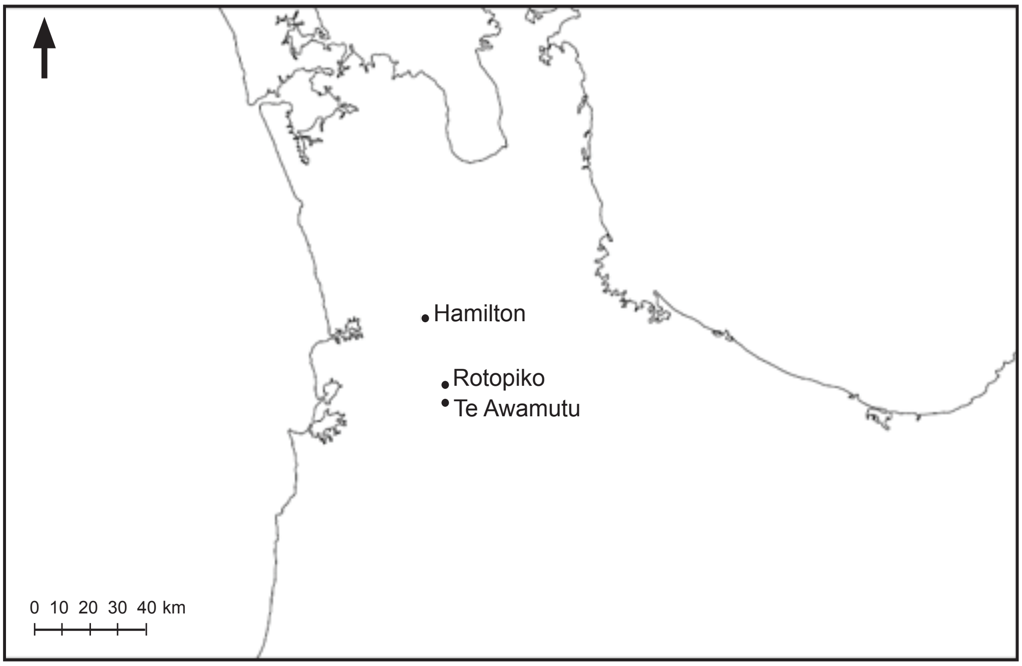

Figure 1. Map showing Rotopiko location in the Waikato region of the North Island of New Zealand.

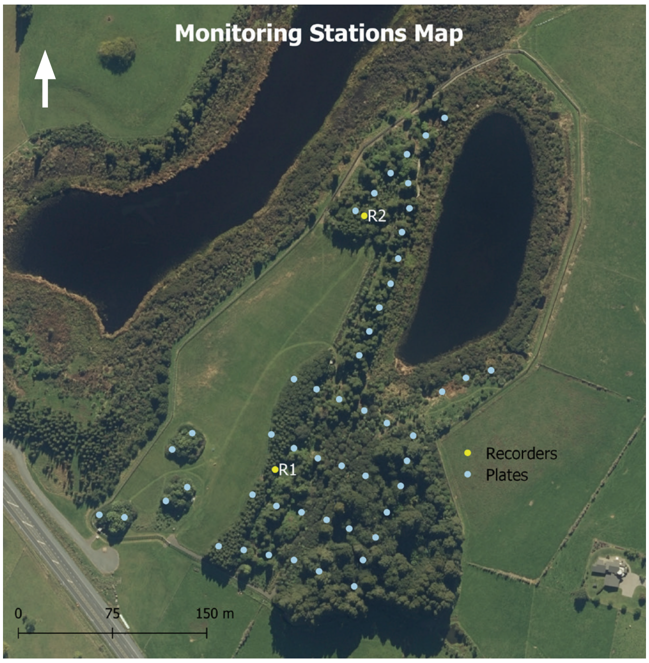

Figure 2. Map of the monitoring stations used to measure bird droppings at Rotopiko and the sound recorder locations.

evidence of heavy roosting. A total of 50 stations were created. At each station plastic plates were deployed to collect birds' faeces which was used as an indirect measure to estimate the relative abundance of the roosting community. The plates were made from 2mm thick green polypropylene sheets and measured 300 × 300 mm. A nine-module grid was drawn on each side of each plate with permanent marker, with each square measuring 100 × 100 mm. This nine module grid on the plates was critical for measuring change relative to the number of roosting birds instead of a simple presence/absence observation. The stations were distributed 20 m apart.

Data were collected about the roosting and diurnal birds from September 2020 to November 2021. The data from the roosting birds were collected as follow: on each monitoring day, the plates were deployed one hour before sunset. A plate was fastened to the ground at each monitoring station with metal pegs and a flagging tape, displaying the station code, was hung from a branch near each station to ensure the measurements were taken from the same place each time. The following morning, approximately one hour after sunrise, the data were recorded from each plate. Measurements were only carried out on nights/days without rainfall as the bird droppings would have been washed off the plates by the rain. Approximately 35% of potential surveying events were affected by rainfall and excess moisture at ground level. To collect data about diurnal birds, plates were deployed one hour after sunrise after all roosting birds had left the site meaning that only droppings from diurnal birds were deposited on the plates. Data were collected one hour before sunset, before the roosting birds arrived at the site. The plates had grids on both sides which mean that, by flipping the plate, diurnal birds' data could be collected directly after the data from roosting birds were collected. After the data collection, the plates were taken to the lab and cleaned in preparation for the next collection event.

In addition, two AR4 wildlife sound recorders, developed by the Department of Conservation, were deployed each time that the plate measurements were made. The recordings were taken at a sample rate of 32 kHz at 16 bits for one hour, from 30 minutes before sunset to 30 minutes after sunset. The recorders were hung from the same tree branch at each location. These AR4 recorders are generally used in the field to record sounds from species or communities at low densities where individuals are relatively easy to identify. However, for the large congregation of birds at Rotopiko, individuals could not be identified because the bird calls constantly overlapped. The sound from the bird community at Rotopiko was therefore converted into a measurable quantity using the specialised Raven Pro software. Pérez-Granados & Traba (2021) review studies using passive acoustic monitoring to obtain estimates of wildlife population density and abundance, with 31 studies having evaluated the use of sound recorders to estimate bird densities during 2014–2019. The review highlights the capability of sound recorders to estimate bird numbers from individual vocalizations and expressed potential improvements such as assessing the sampling radius of the sound recorder used to improve population density estimates. A particular method reviewed was sound pressure levels (SPL) of bird calls which measures the energy emitted by the call. Yip et al. (2020) specified the extensive fieldwork required by SPL to estimate bird density as data from bird distance to the recorder and robust calibrations are necessary. This research uses the principle of measuring the energy of bird calls but without the limitation of knowing the distance of birds to the recorder, as in Rotopiko the location of the roost is defined, and measures of population density are not pursued. In addition, energy of individual bird calls was not measured per se, rather we measured the energy of the community calls for our research objective.

Data analysis

Each module of the gridded plates grid represented 1/9 (0.11) of the whole plate. Data were recorded by observing the number of modules in the grid that contained bird droppings. For example, a plate with droppings in 4 modules was recorded as 0.44. Then the average from the 50 plates was calculated. Data from the plates for the diurnal and roosting birds were compared at different times of the year, to determine whether changes in the bird community and community fluctuations were detected by the index.

Files (.wav) from the AR4 recorders were analysed using Raven Pro software, which was developed by researchers in the ornithology lab at Cornell University in the United States. Raven Pro includes the option to select advanced measurements from a particular time-frequency recording beyond spectrograms and amplitude graphs. Changes in the bird community were measured with the acoustic energy option, as this gave a quantifiable estimate of the bird community. Raven Pro expresses the ratio of joules per meter square in decibels. The energy was measured at frequencies 4000–9000 Hz, and anthropogenic noise occurring below 4000 Hz was masked. As also reported by Wood & Yezerinac (2006), anthropogenic noise, i.e. from vehicles, was detected in the results from initial data at frequencies below 4000 Hz. Even though some calls of sparrow and starlings are outside the standardised frequency range used, the range captured the calls in the 4000–9000 Hz range. Each monitoring day, the total energy released by the roosting community was recorded for a one minute period 20 minutes before sunset when birds were at their loudest. For the diurnal birds, the energy was measured for a one-minute period eight hours after sunrise. Then, the energy recorded was compared and correlated with the index obtained from the plates.

Statistical analysis

The data were analysed to assess the ability of the developed methods to detect seasonal fluctuations in the roosting community and compare differences between the sizes of the roosting and diurnal communities. Trends from both indices' plates and acoustic energy, were correlated by using data obtained from clearly defined ecological seasons. Seasonal climatic changes regulate different ecological processes in animals such as breeding and reproduction (Kutty 2021). An understanding of the yearly behavioural patterns of the roosting community at Rotopiko was therefore critical for interpreting the data. The distribution characteristics of seasonally distinctive data sets of the roosting community and the abundances of diurnal and roosting birds were compared with box plots. In addition, the 95% confidence intervals for the medians of each group were calculated using the following equation:

$$m \pm 1.57 \times \frac{IQR}{\sqrt{\mathrm{n}}} \qquad (1)$$

where IQR is the inter-quartile range, n is the sample size and m is the median) to estimate whether the data sets presented on the box plots showed indicative differences (Krzywinski & Altman 2014). Finally, Pearson's correlation coefficient was used to determine the extent of the relationship between the two indexes. In addition, 95% prediction interval was calculated to show the range for the Y-values for given specific X-values, and 95% confidence interval to show the range for all potential best-fit lines.

Results

Index trends

The trends in the acoustic energy and gridded plate trends of the roosting population were similar. Energy remained between 50–48 dB in September 2020 and then gradually decreased to 29.3 dB at the end of January 2021, which was the lowest energy recorded in this period (Fig. 3). The energy then increased sharply at the end of February to 40.5 dB, and then increased further to a maximum of 51.3 dB in June 2021. The plate loading rates increased to a maximum 74.4 loading rate in September 2020 and then decreased sharply to a minimum loading rate of 32.0 at the end of November 2020. During the summer months, the plate loads tended to increase but, unlike the energy that remained constantly increasing, the plates showed an irregular increase between 40.9–54.2 loading rate. Mid-autumn, the plates loading rate increased to 77.9 and reached the maximum record for this period of 79.5 loading rate in winter 2021.

Gridded Plates

For roosting birds, the winter-early spring period showed lower variability of the dataset relative to the other two roosting periods. The interquartile range (the middle 50% of the data) of roosting birds increased considerably from 5.1 during the winter-early spring period to 27.7 during the late summer-autumn period. The median loading rate for the roosting community reached a maximum of 72.7 during winter-early spring, then decreased to 41.8 during late spring-early summer and increased again to 53.8 in the late summer-autumn period. Besides the clear differences in the median and interquartile range spreads, the late spring-early summer and winter-early spring periods for roosting birds varied in the overall distribution of the dataset. While the interquartile range for late summer-autumn was larger than late spring-early summer, all the quartiles in the distribution were relatively evenly scattered; however, late spring-early summer tended to be skewed towards high loadings rates. In addition, all the medians for the roosting dataset were outside of the interquartile boxes of the other two periods.

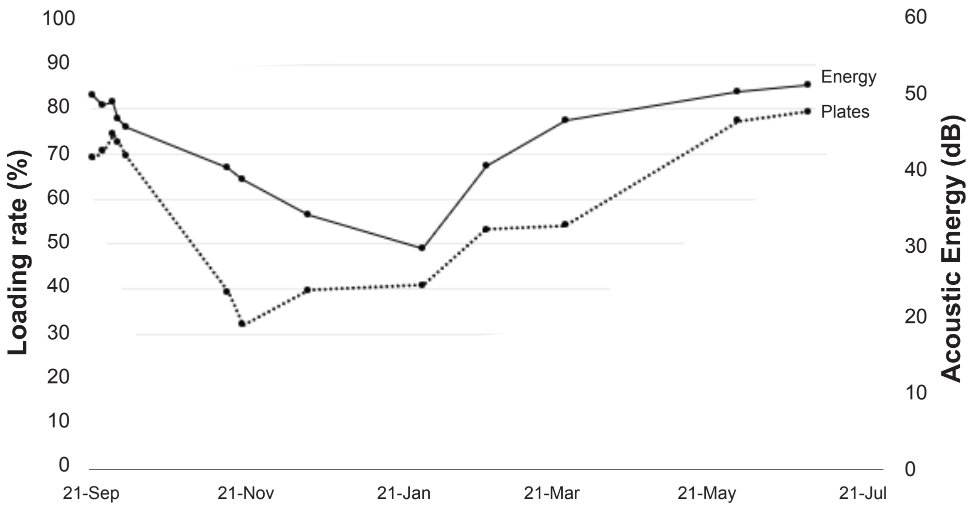

Figure 3. Comparison of the acoustic energy and gridded plate indexes of the roosting community at Rotopiko from September 2020 to July 2021. The solid line shows the acoustic energy in decibels captured by the AR4 recorders and analysed via Raven Pro acoustic software. The dashed line shows the gridded plates loading rate.

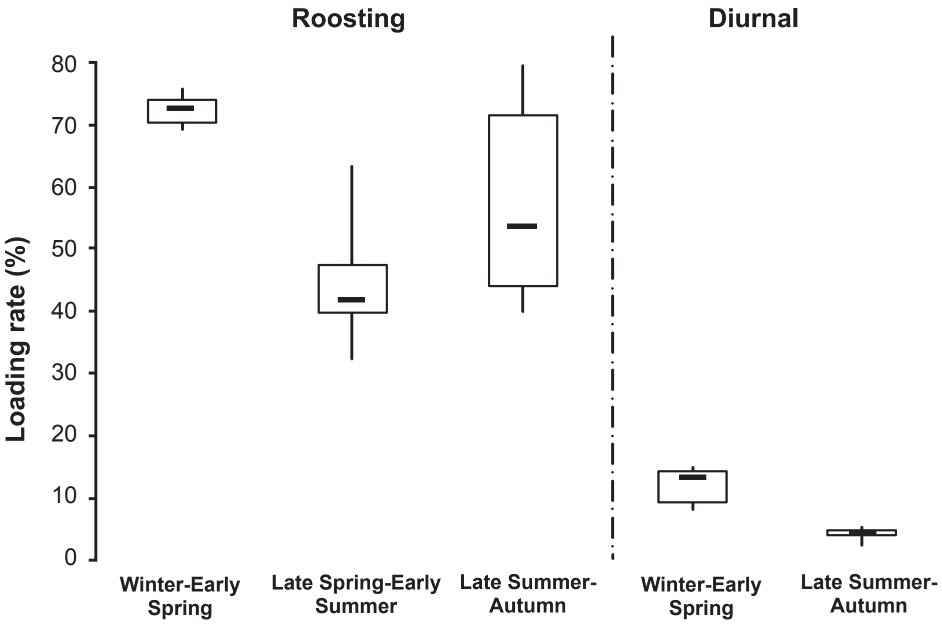

Figure 4. Box plots comparing different distributions from roosting and diurnal birds plates loading rate datasets from winter 2020 to autumn 2021 at Rotopiko. Each period, winter-early spring, late spring-early summer, and late summer-autumn was determined according to the natural fluctuations of the roosting community of birds. Data were collected using the gridded plates developed for this research.

For diurnal birds, data were recorded for two periods, winter-early spring, and late summer-autumn. The interquartile ranges show that the data were more variable, in the winter-early spring (6.3 interquartile range) than in late summer-autumn (0.20 interquartile range). The loading rate median for the winter-early spring period was 13.5 and was higher than the median of 4.7 during the late summer-autumn period. As for roosting birds, the medians for the diurnal birds were outside the interquartile box of the other period and the interquartile boxes of the diurnal birds did not overlap. Comparison of the box plots of the diurnal birds and the roosting birds shows that there is a clear difference in the relative abundance range recorded for each community. For example, the highest loading rate for the diurnal birds was 14.9 and was lower than the lowest loading rate recorded for the roosting birds (32.0). In addition, for the same period in late summer-autumn, the roosting loading rate ranged from 39.7 to 79.5 whereas the diurnal loading rate ranged from 2.2 to 5.6. Similarly, for the winter-early spring period, the roosting birds loading rate ranged from 69.1 to 76.0 and the diurnal bird loading rate ranged from 8.2 to 14.9. The 95 % confidence intervals of the medians confirm the clear differences in the roosting and diurnal groups, as shown in Fig. 4. The table complements the box plot by providing the numerical ranges of the differences between the groups.

Gridded Plates-Acoustic Energy Correlation

The two indexes were strongly correlated and 92.16% of the variation in the acoustic energy was explained by the model. The data show a positive relationship, with an increase in the loading rate accompanied by an increase in the dB measured by the recorder. However, the relationship between the variables seemed to be stronger for high bird numbers than for low bird numbers. Data points were clustered near the regression line when the loading rate was higher than 60% and were further from the regression line when the loading rate was less than 22% (Fig. 5).

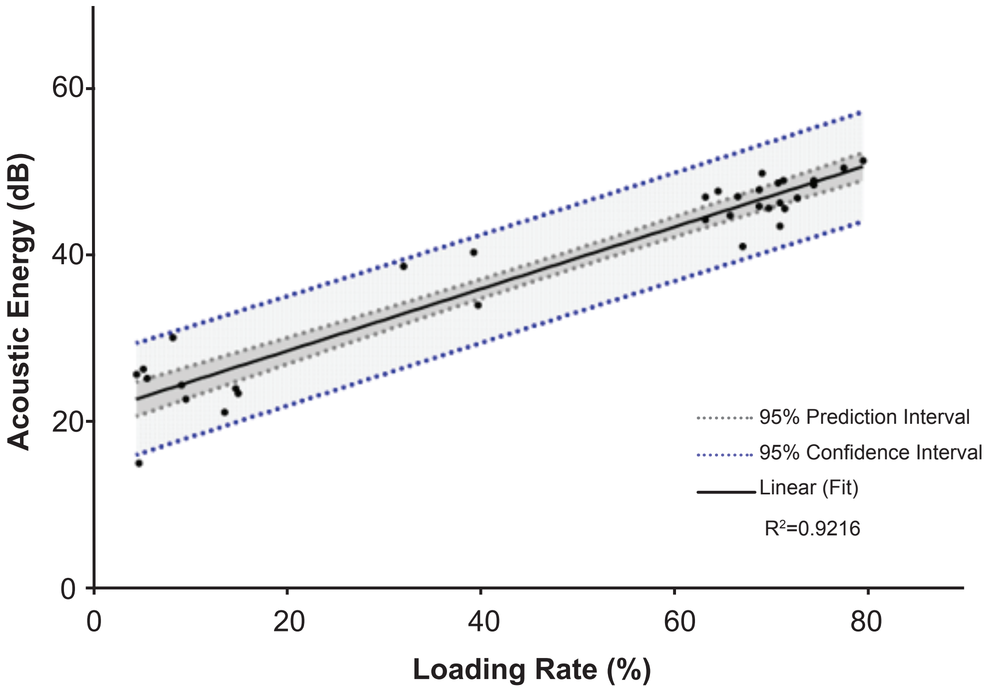

Figure 5. Correlation between acoustic energy (dB) and loading rate (%) measured at Rotopiko from winter 2020 to spring 2021.

Discussion

Initially, the purpose of this research was to develop a method for measuring the size of the roosting bird community at Rotopiko. This was achieved by using plates to collect guano from roosting and diurnal birds and was validated by comparing the results with data from sound recorders. This means that, in this study, two independent methods that are capable of estimating the relative abundance of roosting birds at Rotopiko were developed and the methods effectively measured seasonal fluctuations in the size of the roosting bird community (Fig. 3). Communal roosting of birds helps to minimise predation pressure and maintain body temperature during the winter months (Bijleveld et al. 2010). Rotopiko, as a mammal-free site, offers a low risk of predation and provides a relatively safe place to roost all year round. The seasonal variations in the air temperature in the Waikato (20–25 ºC in summer, 0–8ºC in winter) (Chappell 2013) were reflected in our data, as birds roosted in large groups in the colder months, to reduce thermoregulation costs. The highest indexes levels calculated from the plates and acoustic energy were 74.4 loading rate and 51.3 dB during winter and were 48% (plates) and 43% (acoustic energy) lower in summer, and then increased again when the colder months arrived. The observed seasonal fluctuations align with bird behaviour during nesting and breeding seasons. In New Zealand, the sparrow and starling breeding seasons are between September and February (Dawson 2013) and September and December (Flux 2017). Even though starlings tend to visit the roosting site all year-round, females stay at the nesting sites during the breeding season (Flux 2017). For the roosting community, the decibels of acoustic energy showed a gradual decrease from winter to summer while the plates declined sharply towards December (Fig. 3). This suggests that the plates had limited sensitivity to detect changes in bird numbers as the roosting community decreased.

The distribution patterns shown in Fig. 4 provide an insight into the ability of the guano plates to detect changes in the bird community. The interquartile ranges on the roosting birds box plot were more spread out for the summer months than for the winter months, which suggests that the bird numbers fluctuated more during summer. The late spring-early summer period was less variable than the late summer-autumn but the low bird numbers in this period seemed to skew the distribution, as more data points coincided at the lower end of the distribution. This again reinforce the limited sensitivity of the plates at lower bird numbers. The interquartile range for winter-spring was narrower than for the other two periods in the roosting community, indicating stable bird numbers in this period. However, this could also indicate that the plates reached an upper threshold at approximately 72.7 loading rate. Diurnal birds also showed a narrow interquartile range and a median of 4.7 during summer. According to the medians (Fig. 4), the results from this study therefore suggest that the current plate resolution can measure from a lower threshold of 4.7% to a higher threshold of 72.7%. An alternative reason for the upper limit value could be the shelter space at Rotopiko. The carrying capacity is generally defined as the highest number of individuals in a population that an environment is capable of sustaining at a particular time (Hartvigsen 2017). Chapman & Byron (2018) stated that shelter was a critical factor of carrying capacity models in their review of ecosystem studies.

The interquartile ranges suggested upper and lower threshold limits for the plates and the medians confidence intervals highlighted differences between the datasets. The medians of each group were outside the comparable box plots (Fig. 4), which suggests a difference between the groups. In addition, the difference between the roosting and diurnal bird appeared to be larger according to the contrasting values, with 72.7 and 13.5 in winter-early spring and 53.8 and 4.7 in late summer-autumn for roosting and diurnal birds respectively. The median 95% confidence intervals (Table 1) also suggest differences between the groups as the confidence intervals of the groups do not overlap (Krzywinski & Altman 2014). This finding is important for this study, as it suggests that the plates were able to detect large changes in the bird numbers, such as the differences between roosting and diurnal birds,

Table 1. Comparison of the 95% confident Interval of the plates loading rate medians from the roosting and diurnal communities at Rotopiko. Equation (1) was applied to calculate the confidence intervals where IQR = interquartile range (Q3–Q1).

	Roosting			**Resident**	
	Winter–Spring	**Spring–Summer**	**Summer–Autumn**	**Winter–Spring**	**Summer–Autumn**
IQR	0.17	0.15	1.025	0.65	0.2
Median	72.7	41.8	53.8	13.5	4.7
Sample Size	7	7	6	7	7
95% CI	**(69.7, 75.7)**	**(46.4, 37.2)**	**(71.6, 36.1)**	**(17.2, 9.8)**	**(4.8, 4.6)**

but also detected small fluctuations in the bird communities. The addition of the median 95% confidence interval to imply differences in the group's distribution must be considered cautiously as sample sizes are small and the distributions assumed to be nonnormal. It is recommended to support the observations from medians and IQR to suggest differences between the distributions with median 95% confidence intervals for sample size > 20. However, the data suggest that the efficacy of control methods to either drastically or gradually reduce the pest bird numbers at Rotopiko could be assessed and monitored using the plates.

There was a strong relationship between the two monitoring systems, as shown by the regression analysis and the coefficient of determination (0.9216; Fig. 5), but the relationship between the two systems weakened as number of birds declined. The residuals (distance from the points to the trendline) increased as the values decreased (Fig. 5), the points appear to be more spread-out. Residuals in a regression line represent irregularities between variables (Weisburg 2005). As mentioned previously, the capacity of the plates to measure bird numbers seemed to be affected more by the low bird numbers than the sound recorders. This could explain the greater distance between the points when the indexes estimated low bird numbers. This limitation in the plate system reflects how vegetation prevented droppings from reaching the plates. The effect of vegetation could be analysed further by comparing the trends from the plates and the sound recorders as vegetation has less influence on acoustic energy than the plates. Regarding the confidence bands, the narrow 95% confidence interval band (Fig. 5) provides certainty about the location of the best fit line and the 95% prediction band showed that all values except one at low bird numbers fell between the range predicted for any future individual values.

The pursuit of a tool to measure roosting birds at Rotopiko has resulted in the development of two reliable methods, gridded plates, and acoustic energy, for estimating the relative abundance of a large roosting community. If the gridded plates are used at the same resolution as this study, the methods should be used in tandem as the plates appeared to decrease in sensitivity at low bird numbers. To overcome this limitation, we recommend increasing the resolution of the guano plates by decreasing the size of the modules, so that the length of the grids decreased from 100 to 50mm. This would improve the sensitivity of the plates from 9/9 to 36/36. With higher sensitivity, the plates will be more useful for detecting changes at low bird numbers and will also be more effective at assessing the upper limit measurements. The higher resolution could be applied at the upper limit to determine the potential carrying capacity of Rotopiko as a roosting site. In addition, data from the plates, recorders, and from vegetation growth should be studied to understand how vegetation affects the plates, mainly at low bird numbers. This further research could support the identification of an optimal loading rate threshold that the Rotopiko management team could use as reference.

Roosting exotic birds could potentially evolve as a major challenge for New Zealand as more sites become free of mammalian predators. While the findings of this study are site specific, the guano plates and sound recorders could be implemented to estimate the bird numbers at any site with a roosting bird issue.

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Data and code availability

There is no code associated with this article; the data from this article are openly available at https://doi.org/10.6084/m9.figshare.21424986.v1

Author Contributions

NS conceptualisation, methodology, data analysis, field work, writing original draft and reviewing editing. KD conceptualisation, writing-reviewing and editing. DB methodology and data collection-analysis. SD methodology and data collection-analysis. NF data collection.

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