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SHORT COMMUNICATION

Assessment of pyroligneous acid as a pest bird deterrent in a New Zealand pest-exclusion fenced sanctuary

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Abstract: The creation of predator-free sanctuaries, sometimes enclosed by predator exclusion fences, is a common conservation and restoration tool in New Zealand. One such site, the Rotopiko wetland complex, in Waikato, is challenged with large flocks of non-native house sparrows (*Passer domesticus*) and common starlings (*Sturnus vulgaris*)—an estimated 500 000 birds—that roost within the predator exclusion fence, with the potential to alter nutrient regimes and plant community composition. Here we investigated the use of pyroligneous acid (wood vinegar) as a deterrent to roosting birds. The relative abundance of guano from roosting birds was quantified using guano plates in two equivalent patches of native forest, representing treatment and control sites, before and after the application of pyroligneous acid. In 2021, we found that guano abundance was 10% lower at the treatment site than at the control site after the application of pyroligneous acid (tested over 31 days). In 2022, guano abundance was 15% lower during the first 10 days of application. Our findings suggest that pyroligneous acid has promise as an additional option in the bird pest management toolbox. However, further research is needed to test its efficacy in various contexts, investigate relative impacts on different bird species, and develop application methods that increase the exposure of roosting birds.

Introduction

The conservation of New Zealand's unique and diverse ecosystems is the driving force behind the continual development of novel approaches to protect nature. For example, pest-exclusion fences are sometimes used to exclude non-native mammalian predators that disrupt native species and ecosystems (Burns et al. 2012). Pest-exclusion fenced sanctuaries play a critical role in conservation efforts and are considered vital for projects that aim to restore native biodiversity and ecosystem functioning (Manaaki Whenua – Landcare Research 2021), while also providing educational and recreational opportunities for the public (Innes et al. 2019).

One such sanctuary has been established around the east lake of Rotopiko wetland complex, where restoration work began in 2011, led by the National Wetland Trust. A 1.4 km pest-exclusion fence was established in 2013 to create a wildlife sanctuary that facilitates restoration of native plants and animals, including the removal of mammalian pests such as rats (*Rattus* spp.), possums (*Trichosurus vulpecula*), and mustelids (*Mustela* spp.). However, a perverse outcome of creating this approximately ten-hectare sanctuary has been a sharp increase in the abundance of roosting non-native birds. Within two years of eradicating non-native mammalian pests apart from mice (*Mus musculus*), the abundance of house sparrows (*Passer domesticus*) and common starlings (*Sturnus vulgaris*) roosting within the pest-exclusion fence increased dramatically, reaching an estimated 500 000 birds. The volume of bird guano deposited within the wetland complex each night has the potential to alter nutrient regimes and plant community composition (Irick et al. 2015). For example, native species adapted to low nutrient levels may be replaced by species with high nutrient demands such as raupō (*Typha orientalis*) (Frevola & Hovick 2019). Moreover, non-native plants, such as pokeweed (*Phytolacca americana*), and grasses like Yorkshire fog (*Holcus lanatus*) have increased in cover around bird roosting sites, and field observations at Rotopiko suggest that these species can displace native sphagnum moss (*Sphagnum* spp.) (KD, unpubl. data). To counter the massive increase in roosting bird abundance, the National Wetland Trust have trialled several bird disturbance methods, such as lasers, noise, and non-toxic fogging deterrents, but these have not been successful (KD, unpubl. data), highlighting the difficulty of disrupting established roost sites (Klug & Homan 2020).

The challenge of managing pest birds in urban and rural areas has been widely acknowledged (Klug & Homan 2020; Wang et al. 2020; Furlan et al. 2021). Bird-related damage is estimated to cost the United States agricultural sector over US$1 billion per year (Pimentel et al. 2005). In New Zealand, pest birds were estimated to cause losses to viticulture and arable crops of NZ$20 million and NZ$40 million, respectively, in 2020 (Ministry for Primary Industries 2021).

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Literature on pest birds often emphasises the importance of integrated management programmes because the behavioural characteristics and ecological interactions of birds can make management difficult using a single control method (Lindell 2020). Bird culling operations are often resisted by the public (Linz et al. 2015), while visual deterrents, lasers, and acoustic scarers have effective but short-lived outcomes, with secondary consequences such as noise pollution and impacts on non-target species (Micaelo et al. 2023).

Better results have been generated by chemical bird deterrents, which birds tend not to habituate to (Micaelo et al. 2023). Successful bird management examples in agricultural landscapes include the use of methyl anthranilate, which reduced crop loss by 99% at a Washington State University field research facility (Askham 1992), and anthraquinone, which decreased bird consumption of rice by 93% in southwestern Louisiana, when seeds were treated before sowing (Avery et al. 1998). However, a review also found that chemical deterrents were more effective in laboratory conditions than in field applications (Rivadeneira et al. 2018), highlighting the importance of field trials for testing efficacy. At Rotopiko, methyl anthranilate was trialled for three weeks using a hazing machine, but this had no effect on bird roosting density (KD, unpubl. data).

This study focuses on pyroligneous acid, also known as wood vinegar, a byproduct of biochar manufacturing through wood pyrolysis. Pyroligneous acid is an amber coloured complex solution with a strong, smoky aroma. Composed of 80–90% water, it contains up to 17 phenolic compounds (Theapparat et al. 2015), with acetic acid and phenols identified as the main compounds (Theapparat et al. 2018). At low concentrations, it enhances soil health (as a pH regulator) and plant growth (Yang et al. 2024), and acts as a pesticide at higher concentrations. For example, foliar application of 25% concentration wood vinegar effectively controlled winter weeds in grass (Liu et al. 2021) and it has shown toxicity to invertebrates when applied directly (Strong 1973; Tiilikkala et al. 2010). Despite these concerns, its organic nature and sustainable production from biomass waste make it a potential alternative for bird management.

Our study was motivated by anecdotal video evidence of pyroligneous acid repelling birds from roosting in inner-city trees in Nagano City, Japan. A farmer had observed a reduction in starlings roosting in trees above where pyroligneous acid was being bottled. As a result, Nagano City Council trialled pyroligneous acid application on a city street. The available video evidence suggested that the trial was a success, showing birds avoiding roosting in the trees with pyroligneous acid bottles. However, no quantitative evidence was obtained and there is yet no published test of pyroligneous acid as a bird deterrent.

Our study aimed to assess bamboo-derived pyroligneous acid as a pest bird deterrent in the Rotopiko pest-exclusion sanctuary. The efficacy of pyroligneous acid was assessed by placing diffusion bottles in the canopy at the treatment site and quantifying relative abundance of birds via guano plates before and after application. We hypothesised that there would be no significant differences between the control and treatment sites in relative abundance of guano before the application of pyroligneous acid, but that the treatment would reduce roosting bird abundance, and therefore relative abundance of guano, at the treatment site. We further hypothesised that the efficacy of pyroligneous acid as a deterrent would decline over time.

Methods

Study site

Rotopiko wetland complex is located 5 km from Ōhaupō in the Waipā District, Waikato. The complex spans 40 hectares and consists of three connecting peat lakes surrounded by swampy and peaty wetland margins, and a drained mature kahikatea (*Dacrycarpus dacrydioides*) swamp forest. Rotopiko provides essential habitat for many native and endemic species and is regarded as a taonga (treasure) for Ngāti Apakura, the Māori Iwi who are kaitiaki (guardians) for the lakes. Alongside this cultural value, Rotopiko has high ecological value due to its exceptional aquatic plant community (Wu et al. 2013).

Bird roosting sites at Rotopiko are readily identified by thick beds of guano buildup. Roosting birds appear to favour younger planted forest sites with canopy heights of 2–15 m, dominated by the podocarp species kahikatea and tōtara (*Podocarpus totara*) and angiosperm species like māhoe (*Melycitus ramiflorus*) and mānuka (*Leptospermum scoparium*). Fewer roosting birds and less guano deposition occurs in the taller, mature kahikatea forest.

Study design

Two square patches of c. 10 m tall broadleaf trees (each c. 500 m²), planted in the late 1990s, and separated by approximately 20 m, were selected as study sites (Fig. 1). In May 2021, beginning seven weeks before applying pyroligneous acid, we visited both sites during the late-afternoon (30 minutes before sunset) and night (90 minutes after sunset) to confirm the presence of large numbers of roosting pest birds. Additional day visits confirmed that both sites had similar vegetation composition and terrain.

Satellite imagery and geographic information system software were used to locate suitable monitoring stations within the control and treatment sites. Satellite imagery was used to avoid selecting monitoring locations with heavy visible guano presence, as this would overwhelm the guano plates and limit our ability to detect differences in roosting bird abundance. Stations were systematically arranged at 5 m intervals (Fig. 1). Guano plates were deployed at stations within both sites, while pyroligneous acid was applied only in the treatment site.

Experimental methods

The relative abundance of roosting birds was estimated using the guano plates system (Sandoval et al. 2023). This method indirectly measures bird abundance by quantifying the amount of guano deposited on gridded plates overnight. Plates are made of 300 × 300 mm squares of 3 mm thick green polycarbonate sheets, split into a nine-module grid of 100 × 100 mm squares (Fig. 1). This nine-module grid allows for a more continuous measure of the relative abundance of roosting birds, instead of a simple presence/absence observation (Sandoval et al. 2023). Data were recorded by observing the proportion of modules in the grid with any bird guano present. For example, a plate with guano present in three modules was given a value of 0.33. The mean from all plates combined was used to represent the guano loading rate per site from each sample (i.e. a single monitoring night). Prior to each monitoring night, plates were deployed one hour before sunset by fastening them to the ground using metal pegs. Data were recorded from each guano plate the following morning, approximately one hour after sunrise. Guano plates were then collected and cleaned in preparation for the next monitoring night. Plates were collected for cleaning

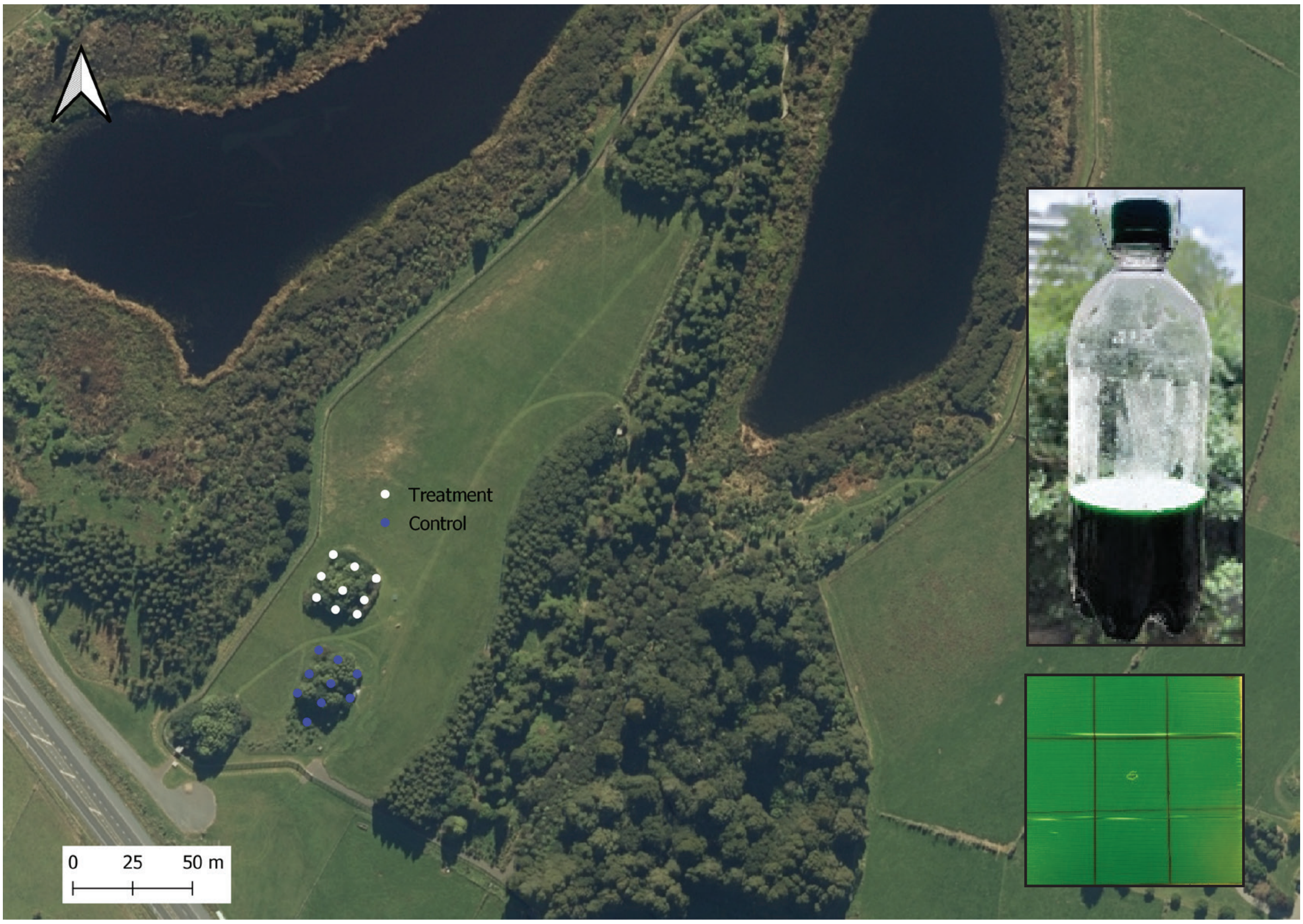

Figure 1. Map of monitoring stations used to measure the relative abundance of guano from roosting birds in the control (blue points) and treatment (white points) sites at Rotopiko wetland complex, Waikato, New Zealand. The top right inset shows the design of the bottles used to deploy pyroligneous acid, while the bottom right inset shows the design of the gridded plates used for measuring guano abundance.

but were not measured if they had been subject to overnight rain or morning dew because this could wash the bird guano away. For one month before applying the pyroligneous acid, bird relative abundance was measured over suitable nights (i.e. without rain or dew) at all 18 monitoring stations ($n = 10$ nights in 2021 and $n = 8$ nights in 2022). The same methods were used during the treatment period.

For the treatment, 750 ml plastic bottles were filled with 100 ml of 100% bamboo pyroligneous acid manufactured by Seek Bio-Technology (Shanghai) Co., Ltd. One bottle was used at each of the nine stations at the treatment site. Six 10 mm diameter fume holes were cut into each bottle, 60 mm below the top and with 20 mm spacing between them. A 20 × 20 cm sheet of cardboard wrapped in plastic tape (for waterproofing) was secured to the top of each bottle to prevent rainwater from entering. A hole was cut in the centre of the cardboard, and it was secured underneath the bottle lid. A 20 cm long wire loop was attached to the top of the bottles, which were hung in trees at a height of approximately 8 m to release pyroligneous acid fumes into the canopy near where birds roost (Fig. 1). To minimise potential neophobic (fear of new things) biases, bottles filled with 100 ml of water were hung in the treatment site for three weeks prior to pyroligneous acid application. During the pyroligneous acid application period, bottles were hung in trees one hour before sunset and left overnight on suitable nights where no rain or dew were forecast. Guano plates were deployed simultaneously. The pyroligneous acid bottles were removed during the day to minimise effects on non-target species. The pyroligneous acid solution was not refreshed during the application period to assess the duration of efficacy.

We conducted two separate experimental trials because the first experiment was disrupted by Covid-19 pandemic restrictions. In 2021, measurements were taken during July on ten suitable nights before the pyroligneous acid treatment and during August on three suitable nights during the treatment. In 2022, measurements were taken during August on eight suitable nights before the pyroligneous acid treatment and during September-October on ten suitable nights during the treatment.

Statistical analysis

To assess the efficacy of bamboo pyroligneous acid as a bird deterrent, we used descriptive statistics and non-parametric tests to compare relative guano abundance between the control and treatment site, calculated before and after the application of pyroligneous acid. Time series of guano relative abundance were plotted to allow visual comparisons among control and treatment sites before and after pyroligneous acid application. Data analysis was also conducted to evaluate the efficacy of pyroligneous acid over time, covering a one-week period in 2021 and a four-week period in 2022 from the start of treatment. Finally, given the small sample size and absence of replicate control and treatment sites, we used the non-parametric Wilcoxon matched-pair signed-ranked test to assess whether the distribution of relative guano abundance differed before and after pyroligneous acid application (Ashcroft & Pereira 2003; Fagerland 2012).

Results

In 2021, median values of relative guano abundance were 10% lower on average during (0.79; proportion of grid squares with guano) than before (0.88) the treatment period in the pyroligneous acid treatment site, with interquartile ranges that did not overlap (Fig. 2a). However, the Wilcoxon signed-rank test was non-significant ($P = 0.28$). In contrast, median values of guano relative abundance did not differ before (0.95) and during (0.94) the treatment period in the control site (Fig. 2a; Wilcoxon signed-rank test: $P = 0.29$). Relative guano abundance trends generally indicated higher guano loading at the control site than at the treatment site, and this difference was more pronounced during pyroligneous acid application (Fig. 3a).

Results were similar in 2022. Median values of guano relative abundance were 12% lower on average during (0.65) than before (0.74) the treatment period in the pyroligneous acid treatment site, with interquartile ranges that again did not overlap (Fig. 2b; Wilcoxon signed-rank test: $P = 0.09$). In contrast, median values of guano relative abundance were similar before (0.89) and during (0.86) the treatment period in the control site (Fig. 2b; $P = 0.53$). The difference (15%)

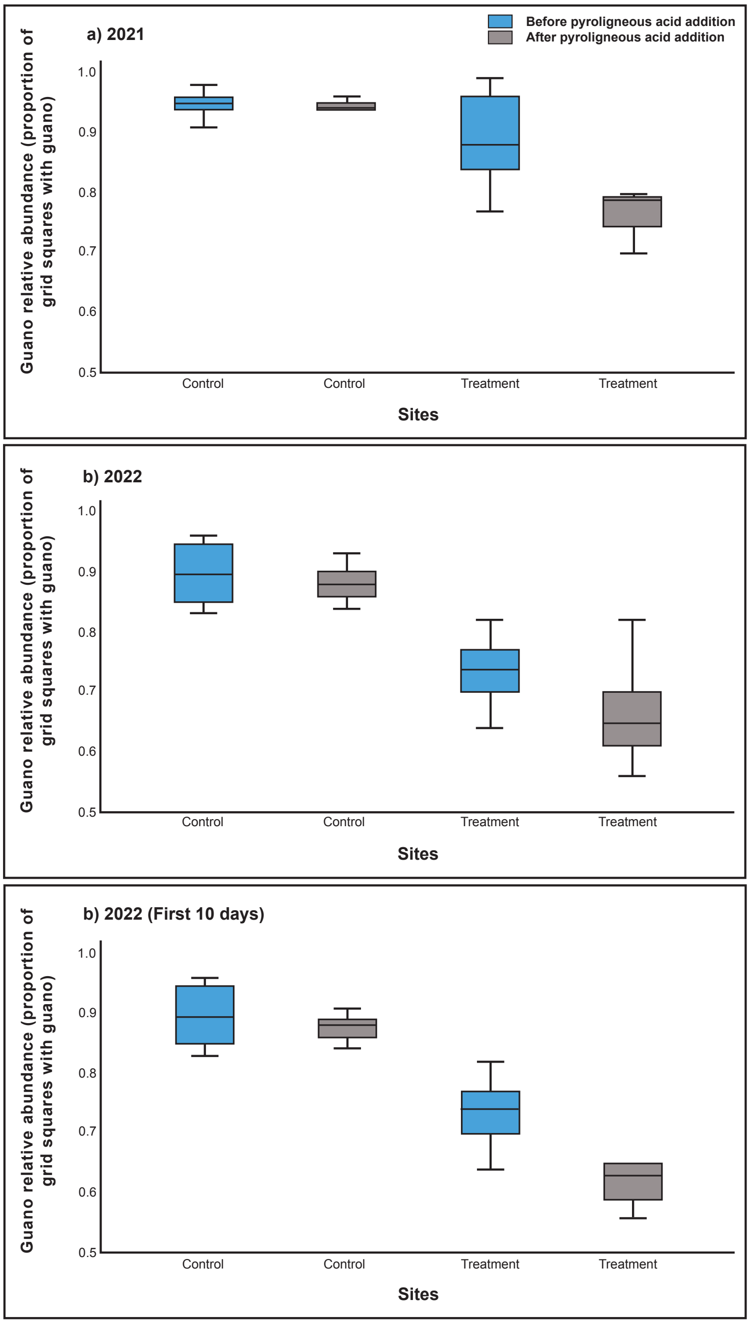

Figure 2. Box plots showing the relative abundance of guano from roosting birds at control and treatment sites at Rotopiko wetland complex, Waikato New Zealand, before (blue boxes) and after (grey boxes) pyroligneous acid application. Relative abundance was measured using the guano plate loading rate (proportion of grid squares with guano). Each box shows the interquartile range, central lines represent the median, and whiskers extend to the maximum and minimum values. a) 2021; b) 2022; and c) data limited to the first 10 days following the 2022 pyroligneous acid application, the period of highest efficacy.

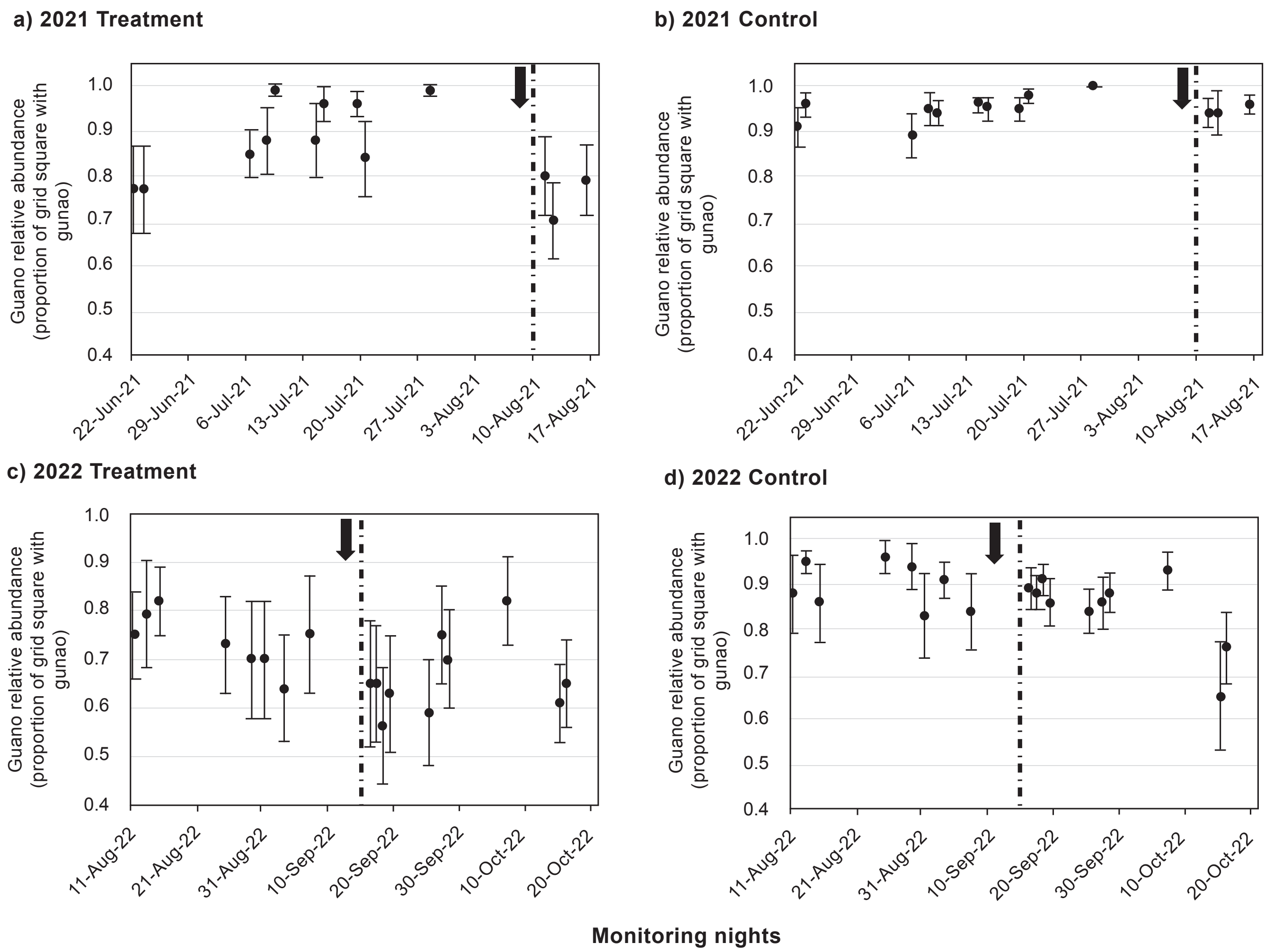

Figure 3. Temporal trends in the mean relative abundance (± 1 SEM, n = 9) of guano from roosting birds at Rotopiko wetland complex, Waikato, New Zealand, before and after pyroligneous acid application. Relative abundance was measured using the guano plates loading rate (proportion of grid squares with guano). Dashed vertical lines and arrows indicate the start of the pyroligneous acid treatment. a) 2021 pyroligneous acid treatment site; b) 2021 control site; c) 2022 pyroligneous acid treatment site; and d) 2022 control site.

between before and after application was slightly more pronounced and statistically significant during the first 10 days of treatment application (Fig. 2c; treatment site: P = 0.04, control site: P = 0.22). Finally, temporal trends in guano abundance in 2022 were similar to those observed in 2021. However, the control site exhibited higher relative guano abundance in 2022, with a more fluctuating trend compared to the previous year (Fig. 3).

Discussion

Our results indicate that the application of pyroligneous acid decreased the relative abundance of guano from roosting birds at the treatment but not the control site, supporting our primary hypothesis. We also found tentative support for our secondary hypothesis that the efficacy of pyroligneous acid peaked within the first 10 days and decreased thereafter. This research represents the first use of diffusion bottles with pyroligneous acid fumes as a bird deterrent, and no prior studies are available for direct comparison regarding the 10-day efficacy duration seen in the results. However, aerosol bird deterrents typically exhibit efficacy ranging from hours to days, influenced by factors such as weather conditions (e.g. wind) and habituation of target species (Engeman et al. 2002; DeLiberto et al. 2024).

We found that pyroligneous acid influenced bird behaviour, though not as effectively as was observed in Nagano, Japan, where starlings completely avoided treated areas. Although aerosol-applied chemical bird deterrents are well-documented, their efficacy varies with species, landscape, and treatment frequency (Vogt 1997; Engeman et al. 2002; Micaelo et al. 2023). Birds generally do not acclimate to chemical repellents (Micaelo et al. 2023), although the effectiveness of such deterrents may vary depending on the context. For instance, a laboratory study in the United States found that European starlings were not deterred by the odour of methyl anthranilate (Clark 1996). However, a field study in Pennsylvania demonstrated successful repulsion of starlings during pear harvest using methyl anthranilate, achieved through four aerosol applications over two weeks (Vogt 1997). These contrasting results highlight how environmental conditions and application methods can influence bird acclimation to chemical deterrents. Although pyroligneous acid fumes lack direct empirical study, the effectiveness of other aerosol chemical deterrents (such as Vogt 1997 and Micaelo et al. 2023) offers a relevant comparison. Effective repellents rely on learned stimulus-response associations, where birds associate a specific stimulus with an adverse outcome, leading to behavioural avoidance (Clark & Avery 2013). Our findings suggest that pyroligneous acid may require reapplication every 10 days to maintain its efficacy in promoting such avoidance behaviours.

The slight decrease in guano relative abundance at the control site over time, coinciding with the larger decrease at the treatment site, may reflect seasonal shifts in roosting behaviour from winter to spring. The observed temporal trends in relative abundance align with typical patterns of higher communal winter roosting, which enhances foraging efficiency, predator avoidance, and thermoregulation when conditions are more challenging (Wang & Chu 2021). The slightly higher overall guano abundance at the control site may arise from its proximity to other roosting areas in Rotopiko. Future trials should alternate pyroligneous acid treatments between sites to account for location preferences or expand the study to include additional sites affected by roosting birds. At Rotopiko, the roosting community comprises approximately 30% common starlings and 70% house sparrows (KD, unpubl. data). Sparrows typically roost in lower vegetation (c. 20 m), while starlings favour taller forest (c. 50 m). The lower reduction in bird roosting compared to Nagano City may arise from pyroligneous acid being less effective on sparrows than starlings. Alternatively, the short duration of our trial may have limited its impact on the estimated 500 000 roosting birds. As the forest reaches roosting capacity, different individuals may alternate between treatment and control sites, reducing consistent exposure to the deterrent. At large roosting sites, individual birds may roost in different trees due to variations in social hierarchies, territorial disputes, weather conditions, or shifts in food availability (Beauchamp 1999; Laughlin et al. 2014). Therefore, prolonged trials may improve efficacy by increasing exposure to more of the roosting population.

Integrated pest management is often recommended for controlling pest birds, and our study provides initial evidence that pyroligneous acid could be a promising addition to the management toolkit. However, further research is needed at Rotopiko or similar sites, such as Opouahi Kiwi Crèche in Hawke's Bay, where large starling flocks have also been observed roosting (W. Allen, Manaaki Whenua – Landcare Research, pers. comm.). Key future research priorities could include quantifying the distribution and ratio of starlings and sparrows at Rotopiko to assess species-specific effects of pyroligneous acid, examining how landscape features like terrain, wind, and vegetation influence fume dispersion (Tegen et al. 2018; Xing et al. 2019), and deploying water-filled bottles at control sites to account for their potential impact on bird behaviour. Additionally, future trials should evaluate treatment effectiveness over longer durations and with more experimental units to further investigate the efficacy of pyroligneous acid and the timing of any decline in its efficacy.

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Additional information and declarations

Ethics: Our study was authorised by the Waikato Institute of Technology Animal Ethics Committee (Protocol Number-104).

Data and code availability: The data from this article are openly available at https://doi.org/10.6084/m9.figshare.25807189. There is no code associated with this article.

Author contributions: NS: conceptualisation, methodology, data analysis, field work, writing original draft and editing. KD: conceptualisation, reviewing and editing. HS: methodology, data collection and analysis. SD: methodology, data collection and analysis.

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

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