BTO RESEARCH REPORT 798

# Understanding statistical power in passive acoustic monitoring of bats: evaluating survey and sampling protocols in the Bailiwick of Guernsey

Stuart E. Newson, Philipp Boersch-Supan & Philip W. Atkinson

BTO Birds Science People

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## Executive summary

Effective biodiversity monitoring requires survey designs that balance volunteer feasibility with sufficient statistical power to detect meaningful population change. Here we use data from the citizen science-led Bailiwick Bat Survey (2021–2024) to evaluate alternative passive acoustic monitoring protocols for bats in the Channel Islands, with a focus on Guernsey, Alderney, and Sark.

Using verified acoustic identification for bat species, we simulated 25-year monitoring datasets under scenarios of 5–25% population declines and compared the power of alternative designs to detect long-term trends.

Simulations applied binomial thinning to impose realistic declines, with bootstrap resampling across sites and nights of recording.

For Guernsey, surveying 100–200 500-m squares annually (36–72% of available sites) would provide ≥80% power to detect 25% declines in five species, including Grey Long-eared Bat *Plecotus austriacus*, Brown Long-eared Bat *Plecotus auritus*, Natterer's Bat *Myotis nattereri*, Common Pipistrelle *Pipistrellus pipistrellus*, and Kuhl's/Nathusius' Pipistrelle *Pipistrellus kuhlii*/*P. nathusii* treated as a cryptic species pair. Changes in power with additional nights of recording per site were negligible, compared with clear gains achieved by increasing spatial coverage.

On Alderney and Sark, complete island-wide coverage allowed 25% declines to be detected in four and two bat species respectively, but sample size limitations constrained power for scarer species. Scarce or range-restricted species (e.g. Horseshoe bats, Whiskered/Brandt's Bat *Myotis mystacinus*/*M. brandtii*) would require targeted roost and swarming site monitoring in addition to landscape-scale surveys.

Our findings demonstrate how citizen science acoustic surveys can underpin statistically robust monitoring of bat populations, while highlighting the importance of representative sampling designs and geographic coverage.

The analyses provide a template for developing a Channel Islands-wide bat monitoring scheme and offer transferable insights for other small-island contexts where resources and site numbers are constrained.

# Introduction

Bats represent one of the most diverse and ecologically significant groups of mammals, providing essential ecosystem services such as insect pest control (Kunz *et al*. 2011). Yet despite their importance, bat populations across Europe and globally remain poorly monitored compared with other vertebrate groups, in part due to their nocturnal behaviour, wide-ranging ecology, and difficulties associated with direct observation. Passive acoustic monitoring (PAM) has transformed the study of bats in recent decades, enabling large-scale, non-invasive sampling of species' presence and activity as a measure of relative abundance through automated recording of echolocation and/or social calls (Hayes *et al*. 1997, Russo & Voigt 2016). Increasingly, citizen science initiatives are central to deploying PAM networks at scales necessary for ecological inference, delivering both high volumes of data and opportunities for public engagement (Newson *et al*. 2015, 2025).

In the Bailiwick of Guernsey, bats make up more than half of the terrestrial mammal fauna, yet basic knowledge of their status, seasonal ecology, and long-term population trends remains limited. As highlighted in Guernsey's *Strategy for Nature* (States of Guernsey 2020), establishing robust biodiversity baselines and monitoring frameworks is a priority for guiding environmental policy, land-use planning, and conservation management. Bats are of particular policy relevance given their sensitivity to habitat change, light pollution, and climate impacts, making them key indicators of ecosystem health. However, the small size and geographic isolation of the Channel Islands present unique challenges: sampling effort is constrained by the finite number of available sites, while rare or range-restricted species may only occur in a handful of locations.

The Bailiwick Bat Survey (2021–2024), funded by the States of Guernsey and coordinated by the British Trust for Ornithology and staff from La Société Guernesiaise, demonstrated the feasibility of volunteer-led PAM across the islands comprising the Bailiwick of Guernsey (Guernsey, Alderney, Sark and Herm), with recorders deployed across hundreds of 500-m squares each year (Newson *et al*. 2025). This effort has already provided the first systematic island-wide baselines of bat activity, but translating such citizen science initiatives into sustainable long-term monitoring requires careful design. In particular, survey protocols must balance logistical feasibility with statistical power: the ability to detect ecologically meaningful population changes with confidence (Taylor & Gerrodette 1993, Legg & Nagy 2006). Power analysis therefore plays a critical role in determining the minimum sampling effort required to detect declines of varying magnitude over time, informing both investment decisions and scheme design.

Despite widespread use of PAM in bat research, few studies have rigorously evaluated the statistical power of alternative survey designs at the landscape scale, especially in small-island contexts. Key questions remain over how many sites and nights of recording are required to detect population declines, how power varies across species with different abundances, and whether increasing temporal replication (more nights per site) is more effective than increasing spatial coverage (more sites). For conservation practitioners, answering these questions is crucial to ensure that scarce resources are deployed where they maximise the probability of detecting trends before populations reach critical thresholds.

Here, we use data from the Bailiwick Bat Survey to evaluate the statistical power of alternative monitoring designs for detecting long-term trends in bat activity. Specifically, we simulate 25-year monitoring datasets for bat species across the three larger islands in the Bailiwick of Guernsey — Guernsey, Alderney, and Sark, imposing declines of 5%, 10%, and 25% over 25 years. We assess the influence of survey effort (number of sites and nights of recording) and species activity on power, with separate analyses for breeding and post-breeding seasons. By doing so, we provide an evidence base for designing a Channel Islands-wide bat monitoring scheme, while generating insights that are transferable to other small-island and citizen science monitoring contexts.

## Methods

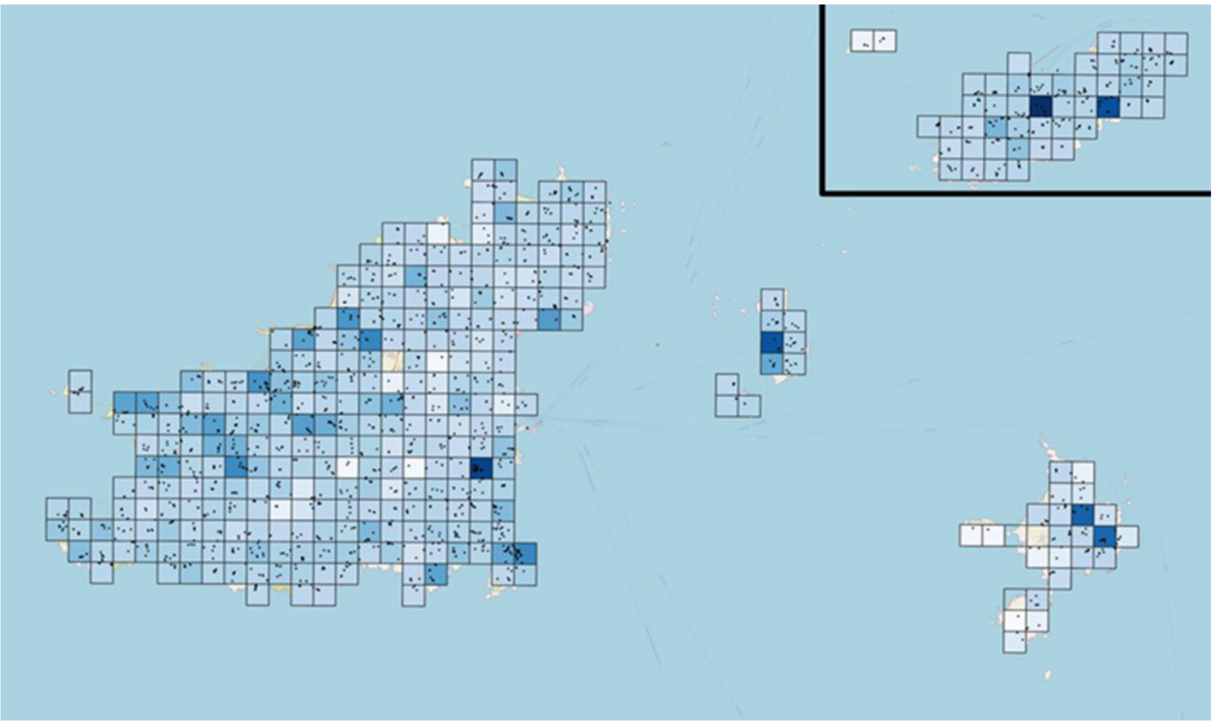
### Study design and objectives

We evaluated the statistical power of alternative passive acoustic monitoring designs to detect long-term trends in bat populations across the Bailiwick of Guernsey. Our analyses focused on the three largest islands – Guernsey, Alderney, and Sark – where sufficient survey effort was achieved during the Bailiwick Bat Survey (2021–2024). The objective was to identify the minimum number of sites and nights of recording required to detect population declines of 5%, 10%, and 25% over 25 years with ≥80% power, a commonly accepted benchmark for ecological monitoring (Taylor & Gerrodette 1993, Barlow *et al.* 2015).

### Data collection protocol

Acoustic data were collected using Wildlife Acoustics Song Meter Mini Bat recorders, deployed by volunteers across 500-m × 500-m grid squares (Figure 1). Recorders were set to record in full spectrum with a sample rate of 256 kHz and to use a high pass filter of 12 kHz which defined the lower threshold of the frequencies of interest for the triggering mechanism. Recording was set to continue until no trigger was detected for a two second period up to a maximum of five seconds. Recorders were deployed before sunset and detectors set to switch on and record from sunset until sunrise, and to record over a minimum of four consecutive nights (mean 4.4 nights). Multiple nights of recording are likely to smooth over stochastic and weather-related variation, whilst also being easy to implement logistically (once a detector is on site, it is easy to leave it in situ for multiple nights). Song Meter Mini Bats were mounted on 2-m poles to avoid ground noise and reduce recordings of reflected calls. Surveys ran from the beginning of April to the end of October in each year, with a small amount of recording outside this period. Two datasets were created: one standardised to four continuous nights per site, and a second to seven nights (with resampling used where fewer nights were available).

**Figure 1. Map showing the original 500 x 500-m Bailiwick Bat Survey squares and the location from which recordings were received. The shading of the squares reflects the number of nights of recordings that were received for each square.**



**Seasonal stratification**

Given differences in ecology and detectability between breeding and post-breeding periods, analyses were run separately for mid May to mid July ('breeding') and mid July to early November ('post-breeding'). This approach allowed evaluation of whether survey timing influenced the ability to detect declines, but with the main interest in resident species during the breeding season.

**Simulation of long-term monitoring data**

We simulated 25-year monitoring trajectories for each species–island–season combination. Three decline scenarios (5%, 10%, 25% over 25 years) were applied corresponding to annual multiplicative survival rates of 0.9980, 0.9959, and 0.9885 respectively according to the below formula – where D is the total proportional decline over 25 years, and (φ) is the annual survival rate.

$$\varphi = (1 - D)^{\wedge}(1/25)$$

Declines were imposed using binomial thinning, which probabilistically reduces counts while preserving observed variance and overdispersion. For each year of the simulation, counts were resampled with replacement from observed site data, thinned according to the cumulative survival rate, and aggregated across sites. This procedure retains the empirical distribution of nightly activity while introducing realistic stochastic declines.

Specifically for each simulated year t, an observed or resampled count $c_t$ was multiplied by the cumulative survival rate up to that year, $\varphi^t$, and the thinned count $c_t'$ was drawn from a binomial distribution:

$$c_t' \sim \text{Binomial}(n = c_t, p = \varphi^t)$$

**Site resampling and bootstrap replicates**

To assess sensitivity to sample size, we simulated surveys of 21, 47, 100, 150, 200, and 250 sites annually. The smaller values represent maximum achievable coverage for Sark (21) and Alderney (47), while higher values were considered feasible for Guernsey. For each sample size, sites were resampled with replacement within island, and the simulation was repeated across 100 random seeds to account for stochastic variability. Within each seed, 10 bootstrap replicates were run per configuration.

**Trend estimation and statistical power**

For each simulated dataset, annual trends were estimated using Poisson generalised linear models (GLMs) with year as a continuous predictor and site as a fixed effect (for >1 site). A significant negative slope ($p < 0.05$) was considered evidence of a detected decline. Statistical power was calculated as the proportion of replicates detecting a decline across seeds. Mean slope estimates and standard errors were also extracted to assess bias and precision.

**Visualisation and interpretation**

Results were aggregated by species, island, season, sample size, and decline rate. Power curves were plotted with ggplot2 (Wickham 2016) to illustrate the relationship between sampling effort and detection probability. Thresholds of 80% power were used to define a 'useful' monitoring design.

# Results

**Influence of spatial replication (number of sites)**

Across all species and islands, statistical power increased steeply with the number of sites surveyed. For Guernsey, ≥100–150 sites were required to achieve ≥80% power to detect 25% declines in the most widespread species including Common Pipistrelle, Grey Long-eared Bat, Natterer's Bat and Kuhl's/Nathusius' Pipistrelle during the breeding season (Figure 2). With 200 sites surveyed annually, power to detect 25% declines in Brown Long-eared Bat during the breeding season with ≥80 power was reached. With 200 sites surveyed, 10% declines in Grey Long-eared Bat and Common Pipistrelle would be possible. In contrast, scarce species (e.g. horseshoe bats *Rhinolophus* species, Whiskered/Brandt's Bat) never approached this threshold, reflecting low detection rates (Figure 2).

On Alderney, full coverage of all 47 sites enabled ≥80% power to detect 25% declines in Common Pipistrelle and *P. kuhlii/nathusii*. Grey Long-eared Bat and Natterer's Bat showed moderate power (60–70%). On Sark, surveying all 21 sites annually provided 80% power to detect 25% declines in Grey Long-eared Bat and 10% declines in Common Pipistrelle.

**Figure 2. Power to detect population declines for the most common and widespread bat species across islands and seasons given four continuous nights of recording. Bars show mean statistical power across simulations for each sample size (x-axis) and decline rate (fill colour). Facets represent species by island and season. The dotted horizontal line marks the 80% power threshold.**

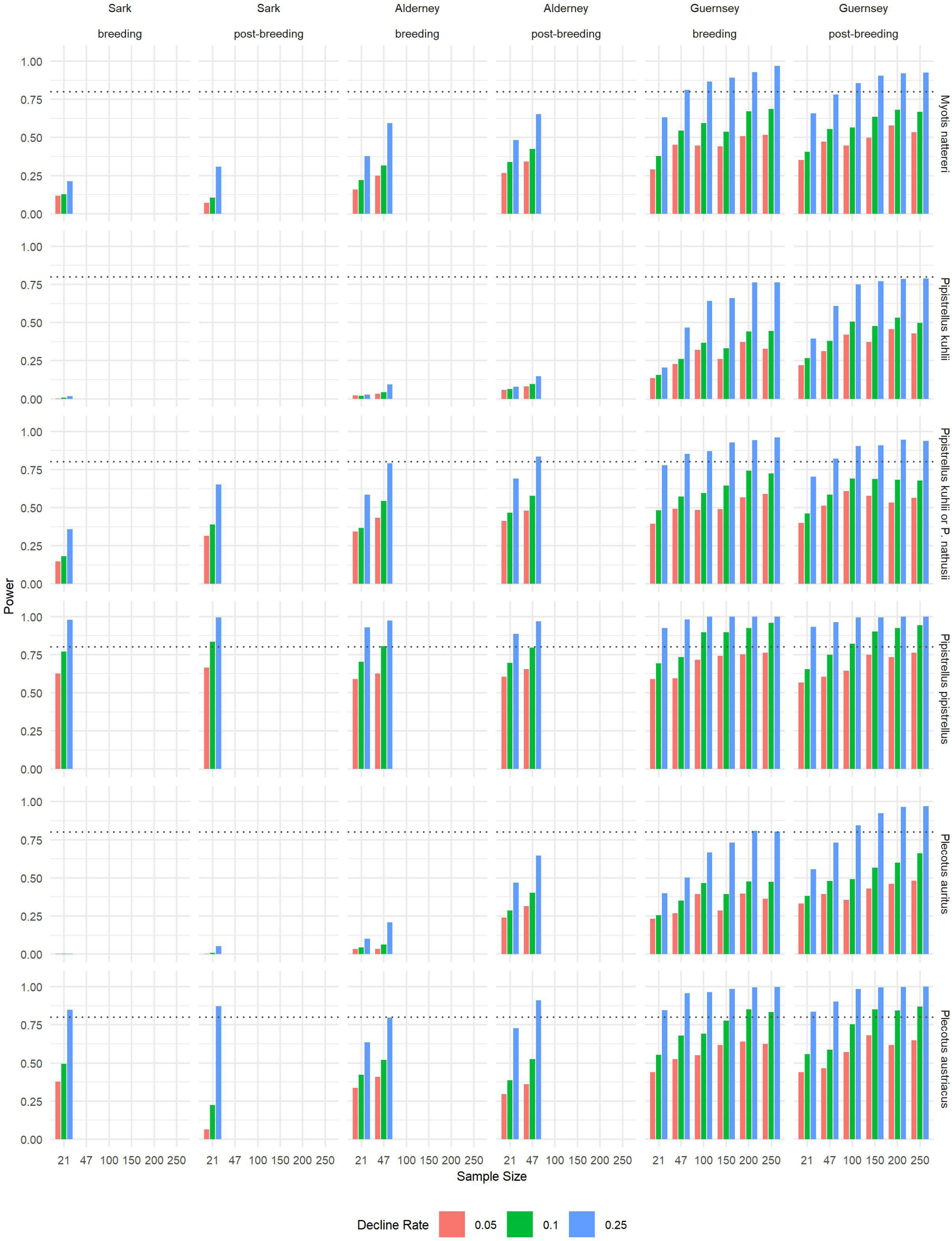
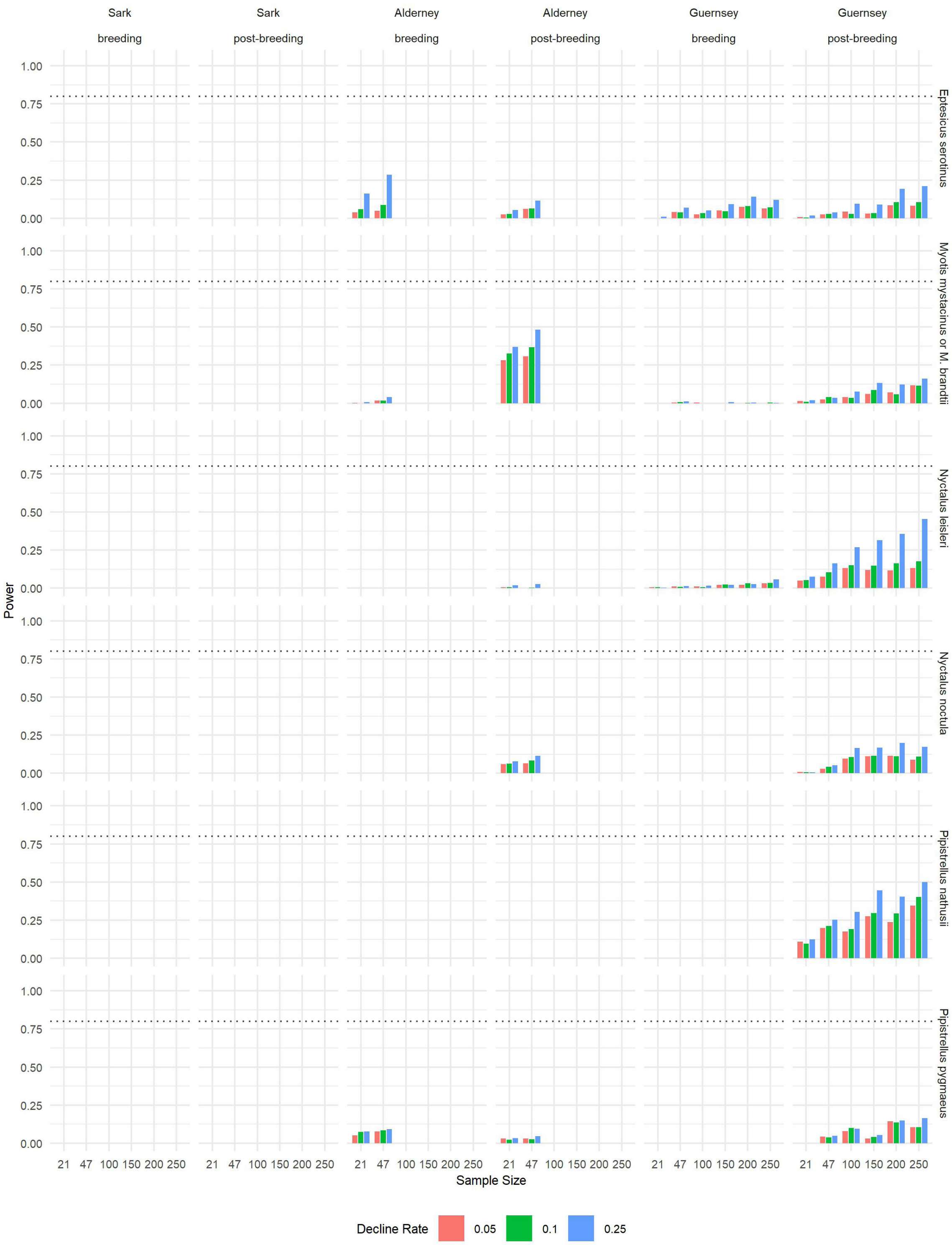
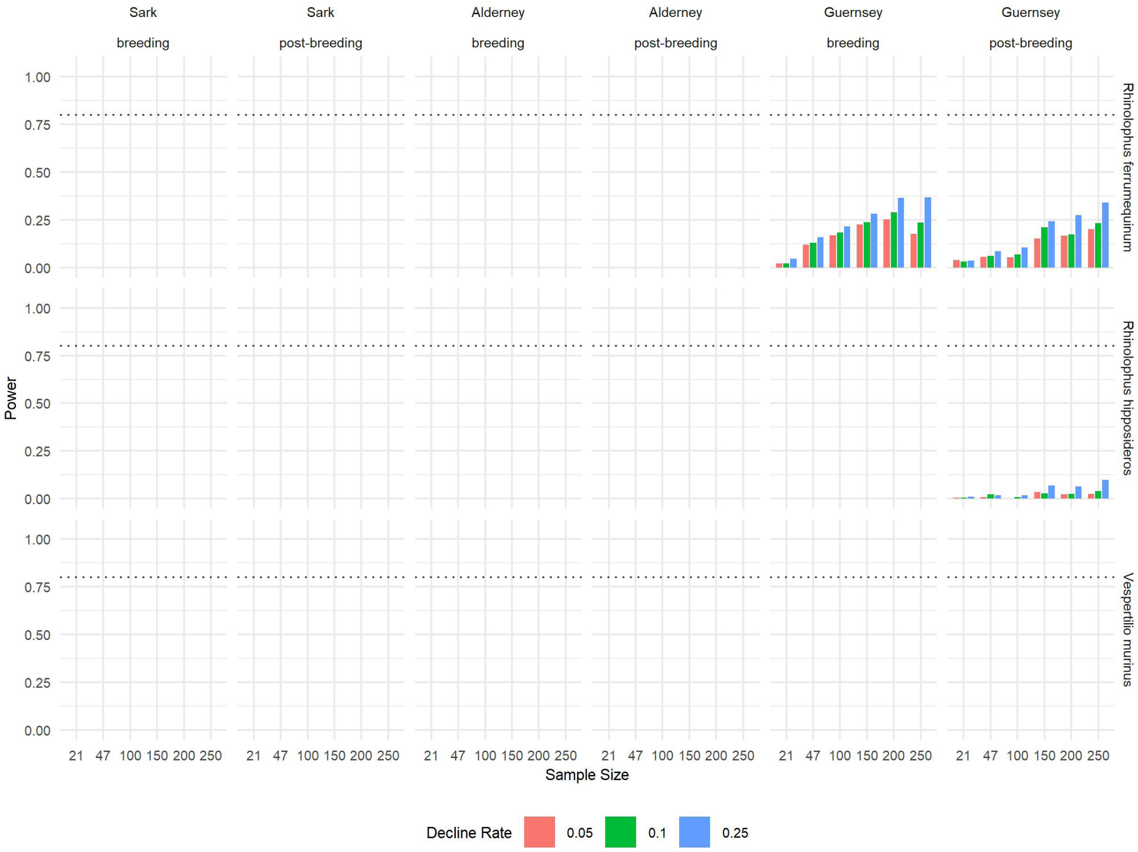


**Figure 3. Power to detect population declines for the more localised or rarely recorded bat species across islands and seasons given four continuous nights of recording. Bars show mean statistical power across simulations for each sample size (x-axis) and decline rate (fill colour). Facets represent species by island and season. The dotted horizontal line marks the 80% power threshold.**




Sark
breeding
Sark
post-breeding
Alderney
breeding
Alderney
post-breeding
Guernsey
breeding
Guernsey
post-breeding
Rhinolophus ferrumequinum
Rhinolophus hipposideros
Vespertilio murinus
Power
1.00
0.75
0.50
0.25
0.00
21 47 100 150 200 250
Sample Size
Decline Rate 0.05 0.1 0.25

### Influence of temporal replication (number of nights)

Increasing survey effort from four to seven recording nights per site produced only some marginal gains in power (typically <10%). However, small reductions in power were as common as gains, particularly where a small number of sites are surveyed (Appendix 1). This indicates that spatial coverage had a much stronger influence on monitoring power than temporal replication.

### Seasonal differences

Post-breeding surveys generally yielded slightly higher power than breeding-season surveys for some species, including for Brown Long-eared Bat, which suggests that post-breeding dispersal may increase detectability of this species. The power was also higher for Kuhl's Pipistrelle post-breeding based on the identification of diagnostic social calls, which are produced more commonly later in the season. However, seasonal differences were smaller than those attributable to sample size or decline rate.

### Detectability of different decline magnitudes

As expected, larger declines were easier to detect. A 25% decline over 25 years was detectable with a high but achievable sampling effort for most widespread species on Guernsey, and for two species each on Alderney and Sark. Detecting 10% declines required much higher site numbers (≥200 in Guernsey) and was generally not achievable on the smaller islands. Five percent declines were beyond detection capacity under all scenarios tested.

## Discussion

### Balancing feasibility and statistical power in small-island monitoring

Our analyses highlight both the opportunities and constraints of implementing a long-term bat monitoring scheme in the Bailiwick of Guernsey. By leveraging citizen science passive acoustic monitoring, it is possible to achieve high levels of site coverage at relatively low cost. However, our power simulations show that robust detection of population declines depends strongly on the number of sites surveyed annually. In Guernsey, a minimum of 100 to 150 sites must be covered (ideally) each year to detect a 25% decline with adequate power (≥80%) for the most widespread species, while 200 sites may be required to reliably detect 10% declines and 25% declines in Brown Long-eared Bat.

If resources are limited, an alternative could be to survey sites intermittently, for example every two or three years. However, the main implication of this will be in the ability to distinguish intermittent year variation in counts from underlying change in bat populations over time, where annual monitoring would be preferable. A decision could also be made to focus on the breeding or post-breeding seasons, or to give some flexibility in the time window within which surveys should be carried out, which would enable the number of bat detectors required to be reduced. For example, to survey 150 sites on Guernsey during the defined breeding season (mid May to mid July, 63 days), allowing a week per site (e.g. weekly bat detector pick up/drop off) would need 17 detectors, plus a few spares to cover failures. For the post-breeding season (mid July to early November), about 10 detectors would be needed to survey 150 sites.

On Alderney and Sark, complete coverage of all available 500-m squares is necessary to approach this level of sensitivity, and even then, power is limited for all but the more widespread species. These findings illustrate a key principle of small-island monitoring: geographic coverage matters more than additional temporal replication at individual sites. There was no evidence that increasing the number nights of recording from four to seven resulted in a consistent and useful improvement in power compared with expanding spatial extent. This conclusion aligns with broader ecological monitoring studies that emphasise the primacy of site replication over temporal effort when designing efficient survey protocols (e.g. Kéry & Royle 2015).

### Implications for designing a Channel Islands-wide scheme

The results provide a template for developing a Channel Islands-wide monitoring framework. On Guernsey, annual monitoring should prioritise a geographically representative network of at least 150 sites, ideally selected using a stratified design that captures key habitats, such as woodland patches, which are disproportionately important for species like Brown Long-eared Bat. On Alderney and Sark, the limited number of sites restricts statistical power, but complete annual coverage still enables useful trend estimation for common species. Importantly, our results suggest that using post-breeding data may increase detection power for some species, including for Brown Long-eared Bat and Kuhl's Pipistrelle, reflecting the seasonal shifts in habitat use observed in the Bailiwick Bat Survey for Brown Long-eared Bat, and a behavioural change for Kuhl's Pipistrelle, where this species produces more social calls post-breeding. For rare species such as the Greater Horseshoe *Rhinolophus ferrumequinum* and Lesser Horseshoe bats *R. hipposideros* and Whiskered/Brandt's Bat, targeted monitoring of maternity roosts, swarming sites, and winter hibernacula would be essential, as landscape-scale PAM is unlikely to deliver sufficient sample sizes.

**Beyond power: representativeness and bias**

While power analysis provides a quantitative benchmark for required sampling effort, scheme design must also address potential biases in site selection and recorder placement. Citizen science projects risk over-representing accessible habitats, such as gardens or urban edges, potentially skewing population trend estimates. Ensuring that survey locations are representative of the wider landscape, either through stratified randomisation or guided volunteer deployment, will therefore be critical. Similarly, consistency in deploying recorders year-on-year to the same point is likely to reduce variance and increase the sensitivity of trend detection beyond the conservative estimates presented here. Integrating explicit design features that minimise bias is important to consider alongside achieving target sample sizes.

**Wider relevance for acoustic monitoring and biodiversity policy**

Analysis of Bailiwick Bat Survey data demonstrates how citizen science PAM can deliver statistically robust monitoring at scales relevant to government biodiversity strategies. This approach is highly transferable to other small-island contexts, where limited site numbers constrain traditional monitoring. Our analysis also reinforces a general lesson for PAM networks globally: increasing geographic coverage is the most efficient way to improve the detectability of population trends. For policy makers, the results provide quantitative evidence that monitoring schemes must be designed with sufficient statistical power to detect declines before they become irreversible, aligning with international biodiversity targets such as the Convention on Biological Diversity and the EU Habitats Directive.

**Future directions**

Building on this work, future efforts should explore:

1. adaptive survey designs that allocate more effort to particular bat species or habitats;
2. integration of acoustic monitoring with other data streams such as roost counts and radio-tracking;
3. the use of hierarchical occupancy–abundance models to combine data across islands and seasons.

Long-term commitment to PAM will also provide opportunities to investigate climate-driven changes in bat activity and phenology, further enhancing the value of the dataset.

## Conclusion

By combining large-scale citizen science acoustic surveys with rigorous power analysis, we demonstrate a practical pathway for developing a sustainable, statistically robust bat monitoring programme in the Bailiwick of Guernsey, with implications for Channel Islands-wide bat monitoring. Ensuring sufficient site coverage, representative sampling, and complementary targeted monitoring for rare species would allow the Channel Islands to establish one of the most comprehensive island-wide bat monitoring frameworks in Europe. More broadly, the study illustrates how carefully designed PAM can underpin biodiversity policy, conservation action, and community engagement in small-island ecosystems.

## Recommendations

Based on our analyses, we propose the following recommendations for the design and implementation of a long-term bat monitoring scheme in the Bailiwick of Guernsey, with wider relevance for Channel Islands biodiversity monitoring:

**1. Prioritise broad geographic coverage.**

- On Guernsey, survey a minimum of 150 sites (500-m squares) annually, with an ideal target of 200 sites, to detect 10–25% population declines in widespread species over 25 years with ≥80% power. If resources are limited, an alternative, could be survey sites intermittently, for example every two or three years, but annual monitoring would be preferable
- On Alderney and Sark, survey all available sites annually to maximise statistical power.

**2. Favour spatial replication over temporal replication.**

- Deploy recorders for four consecutive nights per site as the standard protocol. Increasing the number of nights to seven yields no or little gains; resources should instead be allocated to increasing the number of sites covered.

**3. Adopt representative and stratified site selection.**

- Use randomised or stratified sampling to ensure survey coverage reflects the full range of habitats.

Incorporate habitat stratification on Guernsey (e.g. woodland vs. non-woodland) to improve power for the Brown Long-eared Bat, which has a strong habitat preference.

**4. Implement targeted monitoring for scarce species.**

- Complement landscape-scale PAM with focused surveys of maternity roosts, swarming sites, and hibernacula for rare or range-restricted species, including Greater Horseshoe Bat, Lesser Horseshoe Bat, and Whiskered/Brandt's Bat.
- Employ radio-tracking and trapping to identify key roost sites where necessary.

**5. Maintain consistency and reduce sampling bias.**

- Encourage year-on-year consistency in site locations to reduce variance and improve sensitivity.
- Provide guidance for volunteers on recorder placement to avoid systematic biases (e.g. over-representation of gardens).

**6. Integrate monitoring across seasons.**

- Ideally continue both breeding (May–July) and post-breeding (July–November) surveys to capture seasonal shifts in distribution and to detect migrant species such as Nathusius' Pipistrelle. However, if resources are limited, there may be an argument to focus on the breeding period/breeding population, or to provide volunteers with some flexibility around when surveys can be carried out.

**7. Leverage citizen science and build capacity.**

- Sustain volunteer engagement through clear feedback, training, and community partnerships.
- Consider resuming a network of local 'bat centres' to ensure equitable access to recording equipment.

**8. Future-proof the scheme.**

- Plan for integration of PAM data with other ecological datasets (e.g. roost counts, habitat mapping).
- Explore adaptive designs that focus monitoring effort where early warning of declines is most critical.
- Secure long-term funding to ensure continuity beyond short-term project cycles.

Together, these recommendations provide a roadmap for establishing a sustainable, statistically robust monitoring framework for bats in the Channel Islands, balancing scientific rigour with practical feasibility.

## Management Implications

- **Geographic coverage is more important than temporal replication.** Four consecutive nights of recording per site are sufficient; resources should focus on surveying as many sites as possible each year.
- **Minimum effort thresholds:**
  - Guernsey: Survey ≥150 sites (ideally 200) annually to detect 10–25% declines in widespread species over 25 years.
  - Alderney and Sark: Survey all available sites annually to maximise power.
- **Rare species require targeted monitoring.** Landscape-scale acoustic surveys are insufficient for species such as Greater Horseshoe Bat, Lesser Horseshoe Bat, and Whiskered/Brandt's Bat. Roost surveys, swarming site monitoring, and winter hibernacula counts should be prioritised.
- **Representative sampling reduces bias.** Use stratified random selection of sites (e.g. by habitat type) and consistent site re-use across years to improve sensitivity and representativeness.
- **Multi-season monitoring adds value.** If resources allow, breeding and post-breeding surveys capture seasonal shifts and detect vagrant or migrant species such as Nathusius' Pipistrelle.
- **Citizen science is central.** Volunteer engagement through training, feedback, and accessible equipment hubs is essential for sustaining a high-coverage monitoring scheme.
- **Broader lessons.** The work here provides a transferable framework for other small-island contexts, where resource constraints and limited site availability require efficient and statistically grounded monitoring design.

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**Appendix 1. Power to detect bat population declines in relation to four and seven nights of continuous recording. This table presents the subset of scenarios where there is a 0.8 (80%) power given four or seven nights of survey effort.**

| | | | Power | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Island** | **Season** | **Decline** | **Sites** | **Four nights** | **Seven nights** | **Difference %** |
| *Myotis nattereri* | Guernsey | breeding | 0.1 | 250 | 0.69 | 0.80 | 11 |
| *Myotis nattereri* | Guernsey | breeding | 0.25 | 47 | 0.81 | 0.81 | 0 |
| *Myotis nattereri* | Guernsey | breeding | 0.25 | 100 | 0.87 | 0.94 | 7 |
| *Myotis nattereri* | Guernsey | breeding | 0.25 | 150 | 0.89 | 0.96 | 7 |
| *Myotis nattereri* | Guernsey | breeding | 0.25 | 200 | 0.93 | 0.99 | 6 |
| *Myotis nattereri* | Guernsey | breeding | 0.25 | 250 | 0.97 | 1.00 | 3 |
| *Myotis nattereri* | Guernsey | post-breeding | 0.25 | 100 | 0.86 | 0.93 | 7 |
| *Myotis nattereri* | Guernsey | post-breeding | 0.25 | 150 | 0.90 | 0.96 | 6 |
| *Myotis nattereri* | Guernsey | post-breeding | 0.25 | 200 | 0.92 | 0.97 | 5 |
| *Myotis nattereri* | Guernsey | post-breeding | 0.25 | 250 | 0.93 | 0.97 | 4 |
| *Pipistrellus kuhlii* | Guernsey | post-breeding | 0.25 | 250 | 0.79 | 0.83 | 4 |
| *Pipistrellus kuhlii or P. nathusii* | Alderney | post-breeding | 0.25 | 47 | 0.84 | 0.76 | -8 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | breeding | 0.25 | 47 | 0.85 | 0.87 | 2 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | breeding | 0.25 | 100 | 0.87 | 0.84 | -3 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | breeding | 0.25 | 150 | 0.93 | 0.91 | -2 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | breeding | 0.25 | 200 | 0.94 | 0.88 | -6 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | breeding | 0.25 | 250 | 0.96 | 0.92 | -4 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | post-breeding | 0.25 | 47 | 0.82 | 0.73 | -9 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | post-breeding | 0.25 | 100 | 0.90 | 0.83 | -7 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | post-breeding | 0.25 | 150 | 0.91 | 0.86 | -5 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | post-breeding | 0.25 | 200 | 0.95 | 0.87 | -8 |
| *Pipistrellus kuhlii or P. nathusii* | Guernsey | post-breeding | 0.25 | 250 | 0.94 | 0.90 | -4 |
| *Pipistrellus pipistrellus* | Alderney | breeding | 0.1 | 47 | 0.81 | 0.74 | -7 |
| *Pipistrellus pipistrellus* | Alderney | breeding | 0.25 | 21 | 0.93 | 0.91 | -2 |
| *Pipistrellus pipistrellus* | Alderney | breeding | 0.25 | 47 | 0.97 | 0.98 | 1 |
| *Pipistrellus pipistrellus* | Alderney | post-breeding | 0.25 | 21 | 0.89 | 0.89 | 0 |
| *Pipistrellus pipistrellus* | Alderney | post-breeding | 0.25 | 47 | 0.97 | 0.92 | -5 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.05 | 250 | 0.76 | 0.83 | 7 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.1 | 100 | 0.90 | 0.87 | -3 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.1 | 150 | 0.90 | 0.88 | -2 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.1 | 200 | 0.92 | 0.94 | 2 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.1 | 250 | 0.96 | 0.98 | 2 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.25 | 21 | 0.92 | 0.92 | 0 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.25 | 47 | 0.98 | 0.99 | 1 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.25 | 100 | 1.00 | 1.00 | 0 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.25 | 150 | 1.00 | 1.00 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.25 | 200 | 1.00 | 1.00 | 0 |
| *Pipistrellus pipistrellus* | Guernsey | breeding | 0.25 | 250 | 1.00 | 1.00 | 0 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.1 | 100 | 0.82 | 0.80 | -2 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.1 | 150 | 0.90 | 0.89 | -1 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.1 | 200 | 0.93 | 0.91 | -2 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.1 | 250 | 0.94 | 0.91 | -3 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.25 | 21 | 0.93 | 0.90 | -3 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.25 | 47 | 0.96 | 0.97 | 1 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.25 | 100 | 0.99 | 0.99 | 0 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.25 | 150 | 0.99 | 1.00 | 1 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.25 | 200 | 1.00 | 1.00 | 0 |
| *Pipistrellus pipistrellus* | Guernsey | post-breeding | 0.25 | 250 | 1.00 | 1.00 | 0 |
| *Pipistrellus pipistrellus* | Sark | breeding | 0.1 | 21 | 0.77 | 0.83 | 6 |
| *Pipistrellus pipistrellus* | Sark | breeding | 0.25 | 21 | 0.98 | 0.99 | 1 |
| *Pipistrellus pipistrellus* | Sark | post-breeding | 0.1 | 21 | 0.83 | 0.75 | -8 |
| *Pipistrellus pipistrellus* | Sark | post-breeding | 0.25 | 21 | 0.99 | 0.96 | -3 |
| *Plecotus auritus* | Guernsey | breeding | 0.25 | 200 | 0.81 | 0.78 | -3 |
| *Plecotus auritus* | Guernsey | breeding | 0.25 | 250 | 0.80 | 0.81 | 1 |
| *Plecotus auritus* | Guernsey | post-breeding | 0.25 | 100 | 0.84 | 0.81 | -3 |
| *Plecotus auritus* | Guernsey | post-breeding | 0.25 | 150 | 0.92 | 0.85 | -7 |
| *Plecotus auritus* | Guernsey | post-breeding | 0.25 | 200 | 0.97 | 0.91 | -6 |
| *Plecotus auritus* | Guernsey | post-breeding | 0.25 | 250 | 0.97 | 0.95 | -2 |
| *Plecotus austriacus* | Alderney | post-breeding | 0.25 | 47 | 0.91 | 0.80 | -11 |
| *Plecotus austriacus* | Guernsey | breeding | 0.1 | 200 | 0.85 | 0.81 | -4 |
| *Plecotus austriacus* | Guernsey | breeding | 0.1 | 250 | 0.83 | 0.81 | -2 |
| *Plecotus austriacus* | Guernsey | breeding | 0.25 | 21 | 0.85 | 0.88 | 3 |
| *Plecotus austriacus* | Guernsey | breeding | 0.25 | 47 | 0.96 | 0.88 | -8 |
| *Plecotus austriacus* | Guernsey | breeding | 0.25 | 100 | 0.97 | 0.98 | 1 |
| *Plecotus austriacus* | Guernsey | breeding | 0.25 | 150 | 0.99 | 0.98 | -1 |
| *Plecotus austriacus* | Guernsey | breeding | 0.25 | 200 | 1.00 | 1.00 | 0 |
| *Plecotus austriacus* | Guernsey | breeding | 0.25 | 250 | 1.00 | 1.00 | 0 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.1 | 150 | 0.85 | 0.82 | -3 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.1 | 200 | 0.84 | 0.82 | -2 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.1 | 250 | 0.87 | 0.82 | -5 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.25 | 21 | 0.84 | 0.81 | -3 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.25 | 47 | 0.90 | 0.93 | 3 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.25 | 100 | 0.99 | 0.99 | 0 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.25 | 150 | 1.00 | 0.99 | -1 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.25 | 200 | 1.00 | 1.00 | 0 |
| *Plecotus austriacus* | Guernsey | post-breeding | 0.25 | 250 | 1.00 | 1.00 | 0 |
| *Plecotus austriacus* | Sark | breeding | 0.25 | 21 | 0.85 | 0.82 | -3 |
| *Plecotus austriacus* | Sark | post-breeding | 0.25 | 21 | 0.87 | 0.79 | -8 |

Front cover: Lynda Higgins; back cover: Brown Long-eared Bat, by Chris Damant

## Understanding statistical power in passive acoustic monitoring of bats: evaluating survey and sampling protocols in the Bailiwick of Guernsey

Effective biodiversity monitoring requires survey designs that balance volunteer feasibility with sufficient statistical power to detect meaningful population change. Here we use data from the citizen science-led Bailiwick Bat Survey (2021–2024) to evaluate alternative passive acoustic monitoring protocols for bats in the Channel Islands, with a focus on Guernsey, Alderney, and Sark.

Using verified acoustic identification for bat species, we simulated 25-year monitoring datasets under scenarios of 5–25% population declines and compared the power of alternative designs to detect long-term trends. Our findings demonstrate how citizen science acoustic surveys can underpin statistically robust monitoring of bat populations, while highlighting the importance of representative sampling designs and geographic coverage.

The analyses provide a template for developing a Channel Islands-wide bat monitoring scheme and offer transferable insights for other small-island contexts where resources and site numbers are constrained.

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