Avoid non-probability sampling to select population monitoring sites: Comment on McClure and Rolek (2023)

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FORUM

Avoid non-probability sampling to select population monitoring sites: Comment on McClure and Rolek (2023)

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Abstract

1. Population monitoring programmes typically rely on sampling because it is impossible to survey all the sites within the study area. In such a situation, the general recommendation to obtain unbiased estimates of population trends is to select monitoring sites using probability sampling. However, site selection not based on probability sampling, such as selecting sites with the largest abundance of individuals at the beginning of the monitoring programme, is common in practice. Nevertheless, these methods carry the risk of obtaining biased trend estimates.
2. Using simulations, McClure & Rolek (2023) investigated whether three non-probability sampling site selection methods can yield unbiased trend estimates under some specific conditions. For two of these methods, that is selecting high quality sites and selecting sites known to be occupied, the authors conclude that there is a major risk of obtaining biased trend estimates. For the third method, that is selecting sites with the largest initial abundance, they found conditions in which unbiased estimates can be obtained. They conclude that the general recommendation to use probability sampling should be revised. Here, we show that the authors' results, although perfectly correct, do not invalidate this recommendation.
3. First, we point out that the authors made strong assumptions about the populations' functioning in their simulations, especially that inter-annual variance in abundance is similar for all sites, which is unlikely in most real populations. We show through simple simulations that even slightly relaxing this assumption invalidates the authors' results. We also point out that for most of the hypotheses made by the authors, it is generally not known at the beginning of a study whether they will be respected. Furthermore, the authors did not provide evidence that selecting sites based on high initial abundance leads to more precise trend estimates than probability sampling methods. Therefore, neither the benefits nor the risks of this method are known.
4. We conclude that until evidence is provided that abundance-based site selection improves estimate precision and the situations in which it provides unbiased estimates are clearly identified, using probability sampling should remain the rule.

KEYWORDS
biodiversity conservation, demography, occupancy, population dynamics, population monitoring, sampling strategy, survey design

Most population monitoring programmes rely on sampling because surveying all sites within the study area is usually impossible. In such a situation, it is recommended to select monitoring sites with probability sampling, that is selecting them based on randomness with each site having a known non-zero selection probability, to obtain unbiased estimates of population trends (Yoccoz et al., 2001). However, in practice, sites are often selected through other sampling rules (Olsen et al., 1999; Smith et al., 2017), for instance because they are historically known to be occupied by the target species, because they host large numbers of individuals, or because they are considered high quality sites for the species. This is typically justified by stating that those sites strongly contribute to the overall population trend, or that these sampling methods reduce the number of 'zeros' in the dataset (i.e. sites without any individuals during some years), which is supposed to improve the precision of trend estimates (Blasco-Moreno et al., 2019). Nonetheless, previous studies have consistently demonstrated that these non-probability sampling methods result in biased trend estimates (Fournier et al., 2019; Mentges et al., 2021; Palmer, 1993; Skelly et al., 2003). Such bias can negatively affect research and conservation, for instance by leading to ineffective or harmful decision-making (Burgman, 2005; Regan et al., 2002). Therefore, the unequivocally recommended approach is to use probability sampling to avoid potential biases resulting from site selection.

In a recent article, McClure and Rolek (2023) investigated whether choosing monitoring sites based on their abundance, occupancy or quality always results in biased trend estimates, or if unbiased estimates can be obtained under specific conditions. If the latter was true, these alternative site selection methods could replace probability sampling in situations where the required conditions are met. More importantly, long-term monitoring datasets for which sites were not selected by probability sampling could be analysed without the risk of obtaining inaccurate results. McClure and Rolek (2023) studied three forms of site selection bias using simulations: when sites are chosen based on their initial occupancy (a situation called by the authors 'missing zero effect'), on their high initial quality ('preferential sampling') or on their high initial abundance ('regression to the mean'). For the first two, the authors conclude that there is a major risk of obtaining biased trend estimates. Thus, although not explicitly stated, the article's rationale pleads against selecting monitoring sites based on occupancy or quality, corroborating previous studies. For the third form of site selection bias, i.e. selecting monitoring sites with the highest initial abundances of the target species, the authors conducted simulations using one particular population model. The results show that, under this model, unbiased trend estimates are obtained if inter-annual fluctuations in abundance are small compared to the average difference in abundance between sites. Consequently, the authors conclude that the rule to 'never select sites based on abundance' should not be universally followed.

Here, we question the authors' conclusion and explain why their results, while perfectly correct, do not invalidate the general guideline of not selecting monitoring sites based on abundance. Our first point is that the mere existence of situations in which site selection based on abundance does not lead to biased trend estimates under a given population model is not useful per se to provide clear guidelines for defining sampling designs. To be useful, it must be demonstrated that these situations are not simply a consequence of modelling assumptions, and robust criteria must be provided to identify these situations in practice. Using a simple example, we demonstrate that the authors' results are very sensitive to the hypotheses they formulated in their simulations. Therefore, their study does not allow identifying situations in which selecting sites based on abundance entails a low risk of obtaining biased trend estimates in practice. Second, even if the risk of bias was moderate, there is no evidence in the authors' article that the gain in precision is worth it, or that other probability sampling strategies that aim to reduce the variance of estimates while preserving their unbiasedness would not perform as well.

1 | ARE THE SIMULATED 'BIAS-FREE' SITUATIONS ROBUST TO MODELLING ASSUMPTIONS?

In their simulations, the authors used a phenomenological description of population dynamics in sites based on temporal white noise around a mean abundance sampled in a predefined distribution. The variance around the mean was set as a fixed parameter common to all sites. This modelling choice implicitly carries strong assumptions about the functioning of the studied populations and questions the robustness of the results to other modelling choices (i.e. their structural sensitivity; Adamson & Morozov, 2014). In particular, the mean and variance of population abundances are usually expected to covary in space and time due to density-dependence and environmental synchrony in individual reproduction and mortality rates (Ballantyne & Kerkhoff, 2007; Kalyuzhny et al., 2014). Therefore, the hypotheses used to design the simulations may not reflect the most frequent situations in the field. We replicated the authors' simulations, but instead of setting the standard deviation of inter-annual fluctuations in abundance to fixed levels as they did (i.e. Temporal SD = 10, 100 or 300), we specified it to be equal to the mean abundance of each site, which is the typical pattern of variation for populations subject to environmental stochasticity (Ballantyne &

Kerkhoff, 2007; Kalyuzhny et al., 2014). Under these conditions, 'false alarms' of population decline are triggered for all simulation settings, and the bias of trend estimates increases when the average difference in abundance between sites increases (Figure 1). Therefore, the authors' finding that the skewness of the distribution of abundance between sites should reduce the bias induced by abundance-based site selection is very specific to their simulation choices.

We also conducted simulations for various slopes of the relationship between the standard deviation of temporal fluctuations and mean site abundance. The results show that even small slopes result in biased trend estimates (Figure 2). Thus, selecting sites based on abundance is likely to result in biased trend estimates in many situations, even for long-lived species such as raptors, as mentioned by the authors, where environmental stochasticity might have a relatively small effect on inter-annual fluctuations of abundance. Furthermore, at the start of a monitoring programme it is usually not known precisely how the studied population functions. Thus, it is impossible to be sure that the conditions to obtain unbiased trend estimates from sites selected based on initial abundance will be met.

2 | ARE THE POTENTIAL BENEFITS HIGHER THAN THOSE OF PROBABILITY SAMPLING STRATEGIES?

The primary objective of selecting monitoring sites based on abundance is to improve the precision of trend estimates (McClure & Rolek, 2023). To determine whether this method is of interest, it is crucial to know whether there is a gain in precision compared with alternative probability sampling methods for the same sample size, and how large this gain is. The authors did not provide any assessment of this potential improvement in precision. In addition, their results do not make it possible to assess the proportion of situations in which selecting sites based on abundance leads to biased estimates. Therefore, the risk (i.e. obtaining biased estimates) and the potential gain (i.e. improving the precision of estimates) associated with this approach are currently unknown.

Sampling is a prolific area of statistics, and various probability sampling methods have been designed to address specific situations and improve the precision of estimates while ensuring that they are unbiased (Olsen et al., 1999; Thompson, 2012). In situations where most sites host few individuals and a few sites host

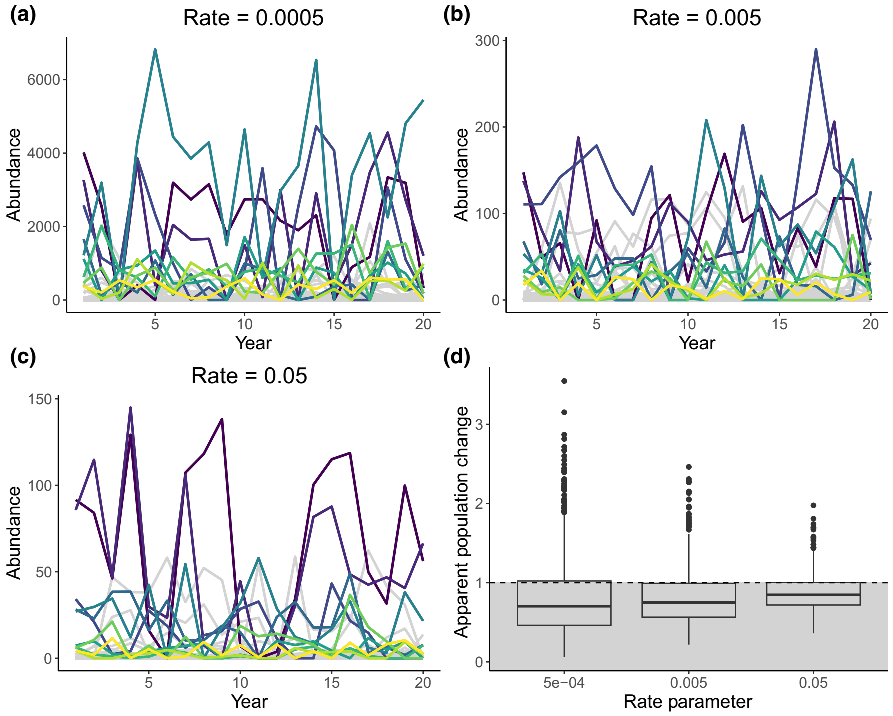

FIGURE 1 Examples of simulated population abundance time series over 20 years at 100 sites with a large difference between the 'high abundance sites' and the other sites (a; rate = 0.0005), a medium difference (b; rate = 0.005) or a small difference (c; rate = 0.05). The standard deviation of inter-annual fluctuations in abundance was set as equal to the mean abundance for each site, that is, the higher the mean abundance of a site, the more its abundance varies between years. The coloured lines represent the 10 sites with the highest abundance in the first year and the grey lines represent the remaining 90 sites. (d) Population trends estimated for stable populations by monitoring the 10 sites with the highest initial abundance for three values of the 'rate' parameter, which controls the average difference in abundance between sites (the smaller rate is, the more individuals occupy the 'high abundance sites'). Boxplots show the estimated population change for 1000 simulations with the same parameter values. An estimated population change of 1 indicates that monitoring the 10 sites with the highest initial abundance provided an unbiased estimate of the population trend. Values <1 (grey shading) indicate that a population decline was detected, while the simulated population abundance was stable, due to the 'regression to the mean' phenomenon.

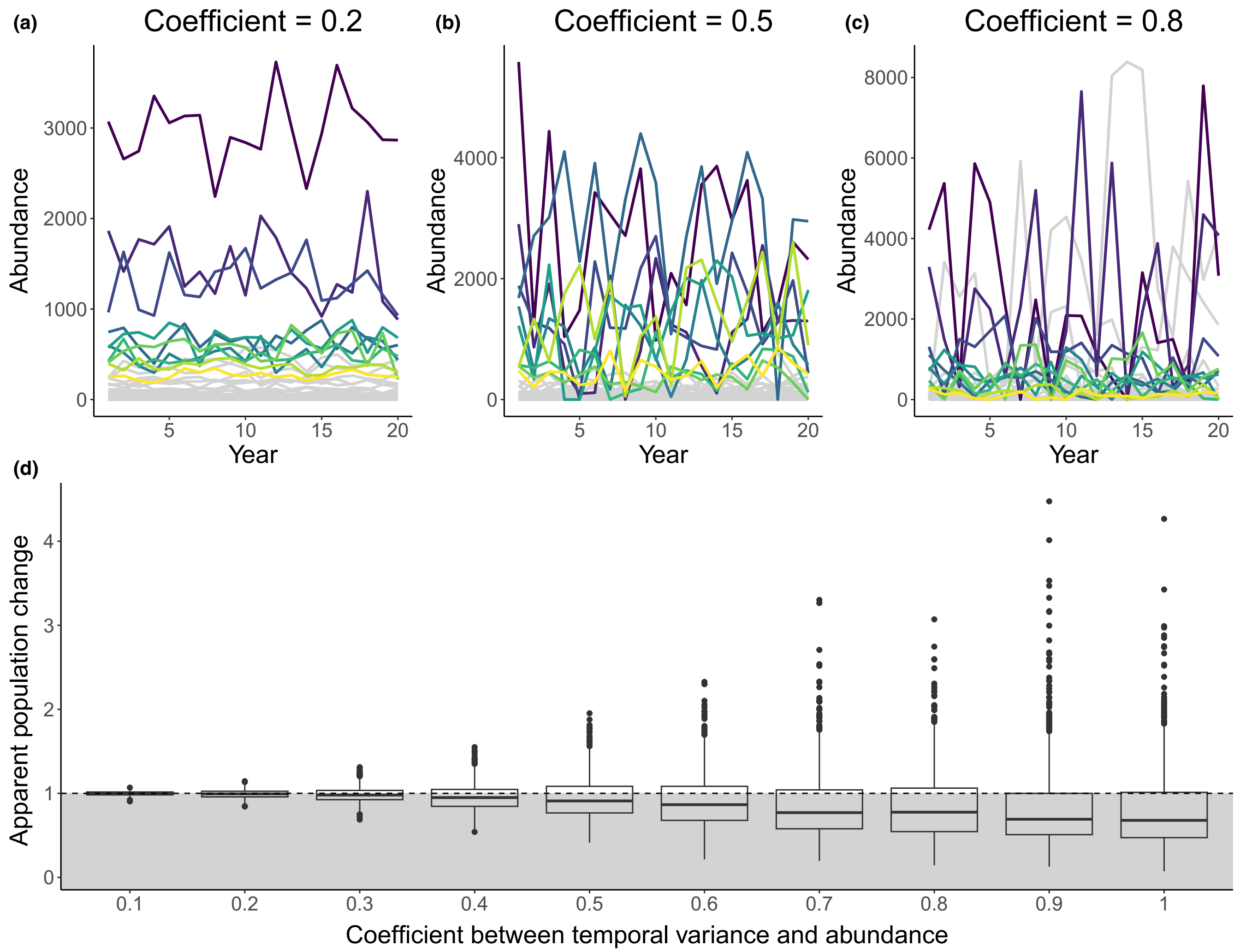

FIGURE 2 Examples of simulated population abundance time series with high average differences in abundance between sites (rate = 0.0005) and a small (a), a medium (b) and a large (c) coefficient between site abundance and temporal variance. (d) Estimated population change for a gradient of coefficients between site abundance and temporal variance (a coefficient equal to one corresponds to that used for Figure 1; all populations were simulated with rate = 0.0005). Values <1 (grey shading) indicate that a population decline was detected, while the simulated population abundance was stable, because of the 'regression to the mean' phenomenon. Values equal to one indicate that the estimated population trend is unbiased.

high abundances (such as those studied by the authors), an effective approach is to rely on stratification, that is to create groups of sites of relatively homogeneous abundance and randomly sample in each group independently (Cochran, 1977). If all the potential sites are known and an estimate of the number of individuals is available for each site, the simplest approach is to define two strata, 'high-abundance sites' and 'low-abundance sites', and randomly select monitoring sites from each stratum. This sampling design ensures that the trend estimate for the whole population is unbiased (see Johnson (2012) and McDonald (2012) for discussions of the pros and cons of this approach). In addition, it makes it possible to estimate a trend for each stratum, which allows for early detection of population declines appearing in the 'low-abundance sites', as described by the authors in the situation called 'preferential sampling'. However, at the beginning of a monitoring programme, it is common that not all potential sites are known, or that only a few 'high-abundance sites' are known, which are sometimes already being monitored. Creating well-defined strata, as mentioned above, is impossible in such situations. However, unbiased estimates of population abundance trends can be obtained by continuing to monitor already known sites, adding a survey to detect unknown sites, and monitoring a sample of the newly discovered sites (see Calenge et al., 2023; for a similar approach to estimate trends in occupancy, see Brown & Olsen, 2013).

3 | CONCLUSION

McClure and Rolek (2023) questioned the 'simple heuristic' of avoiding site selection based on abundance to obtain unbiased population abundance trend estimates. They used simulations to pinpoint putative situations in which little bias would be generated from abundance-based site selection. While the authors' results are undeniable, we showed that they are closely linked to very specific structural assumptions of their model, which might not reflect most natural situations. We also showed that neither the benefit nor the risk incurred by selecting monitoring sites based on high initial abundance are known. Using probability sampling should therefore remain the rule. In very constrained situations where it is impossible to formally sample the entire statistical population, as in some of the examples provided by the authors, we recommend defining a subset of the study area as the statistical population, sampling it following the principles of probability sampling, and drawing (correct) inferences at the level of this subset.

AUTHOR CONTRIBUTIONS

Jan Perret, Fabien Laroche, Guillaume Papuga and Aurélien Besnard conceived the study. Jan Perret programmed the simulations and led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

CONFLICT OF INTEREST STATEMENT

We do not have any conflict of interest.

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PEER REVIEW

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DATA AVAILABILITY STATEMENT

We did not use any data for this article. The R code used to run the simulations is available from the following GitHub repository: https://github.com/JanPerret/Monitoring_site_selection_bias. The repository is also archived on Zenodo https://doi.org/10.5281/zenodo.10030206 (Perret, 2023).

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