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Assessing the communication of bias in UK monitoring schemes

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Summary

The UK has a long history of volunteer-conducted biological monitoring, which now includes several national surveillance schemes that span multiple taxa. These have allowed long-term monitoring of population trends and species diversity, informing conservation policy and management. While large numbers of volunteers facilitate the collection of large quantities of data, the collection is, at least in part, opportunistic. This can result in biases, such as non-random sampling of sites, and changes in sampling effort over time. These biases can make it harder to conduct analyses and draw robust conclusions, as well as undermining the reliability and credibility of data collected by citizen scientists.

How monitoring schemes communicate this bias is therefore extremely important. Effective communication will foster confidence in scheme outputs, allow correct interpretation and further analysis of data, and will increase transparency around data limitations.

This review assessed 26 publicly available documents from six UK monitoring schemes (UKBMS, NPMS, NBMP, BBS, WeBS and PoMS) to determine how effectively bias is being communicated. The biases were categorised as geographic, environmental, taxonomic or "other potential biases", and assessed using the ROBITT Framework (Boyd *et al.* 2020).

Results:

- Bias reporting is often spread throughout scheme documents, with no comprehensive summary, reducing accessibility and potentially leading to uncertainty or false confidence in outputs.
- There is variation in the extent to which bias is identified and assessed between both the schemes and the identified bias domains.
- Where biases are identified, there is rarely an assessment of their likely impact on trends, or information regarding mitigations. Within all domains, there is very little consideration of changes in temporal coverage.

Recommendations:

- Development of a standard format for reporting on bias assessments should be a key priority to improve end-user and stakeholder confidence in data and trends.
- There is a need for clearer identification and assessment of bias domains, particularly those relating to taxonomic coverage and temporal changes within all domains.
- A comprehensive overview of the presence and scale of different biases, and their mitigation, should be provided alongside the annual reports and other publications.
- Steps taken to reduce the impact of bias or uncertainty should be explained to end-users, ensuring compliance with the UK Code of Practice for Statistics.

Contents

1. Background and rationale

Biological monitoring provides information regarding ongoing trends in species diversity and populations which can then inform key management and conservation decisions to combat biodiversity loss (Beever 2006; Ferreira *et al.* 2021). The UK has a long history of monitoring; for example both the 1962 Atlas of British Flora, in which volunteers recorded the distribution of 1,706 plant taxa across the entirety of Britain and Ireland, and the Common Birds Census began in 1962 (Williamson & Homes 1964; Preston 2013), and the BTO Heronries Census of England and Wales is one of the longest-running breeding bird surveys in the world, having been established in 1928 (Marchant *et al.* 2004). There are now numerous national recording schemes covering a range of taxa from plants and fungi to invertebrates, mammals, and birds (Pocock *et al.* 2015). The large number of volunteers participating in these schemes results in the collection of a large quantity of data, but with the caveat that they are largely opportunistic (i.e. recorders choose where, when, what and for how long to sample), which results in non-random sampling of sites and species and uneven sampling effort over time (Isaac & Pocock 2015). Such biases make it harder to conduct robust analyses and draw reliable conclusions regarding change in species populations or distributions. There is increasing awareness of the danger of extrapolating results from biased data or analytical methods (e.g. Cardinale *et al.* 2018; Simmons *et al.* 2019; Guzman *et al.* 2021), and it is clear the limitations of datasets must be considered during analyses. In the medical field, several tools have been developed for assessing the risk of bias in studies (e.g. Higgins *et al.* 2011; Sterne *et al.* 2016, 2019), and within ecology there has been the recent development of the 'Risk-Of-Bias In studies of Temporal Trends in ecology' (ROBITT) tool (Boyd *et al.* 2022), which encompasses a set of questions designed to extract information regarding potential biases within studies, with the purpose of preventing researchers from making inferences that aren't supported by their data.

Many of the biases present in unstructured 'ad-hoc' surveys can be reduced using systematic monitoring schemes. These continue to make use of volunteer efforts to sample what would otherwise be a prohibitively expensive and time-consuming number of sites but introduce strict rules regarding the location of sites and sampling methodologies employed. The JNCC currently supports several systematic monitoring schemes which provide valuable data to assess trends in the distribution and/or population of a range of taxa in response to broad scale environmental and anthropogenic drivers (JNCC 2022). These schemes are thus key contributors to our understanding of status and trends in UK biodiversity, and most are major components of the UK biodiversity indicators, which track progress toward meeting national biodiversity targets (Defra 2021).

UK systematic monitoring schemes are designed to be robust and meet official guidelines on data quality. Survey design may vary based on the specific objectives of each scheme (see Table 1), but they generally implement a random stratified approach, sampling 1 km grid squares within which a standardised sampling method is followed. For example, the Breeding Bird Survey (BBS) utilises a random stratified design, with volunteers recording bird counts along fixed transects within assigned grid cells on two separate days each year (Harris *et al.* 2021). The National Plant Monitoring Scheme (NPMS) has a similar but subtly different design which utilises up to five small, fixed plots situated on a systematic grid within each site, with volunteers asked to visit the plots twice a year and record plants from a predefined list of candidate indicator species (Walker *et al.* 2015).

The design of these schemes attempts to maximise the representativeness of the data for the population/taxa of interest, and significant effort is made to minimise bias in scheme design and to implement mitigation measures during analyses. Despite this effort, however, it is possible that residual bias may remain. Often this may be unavoidable, and, in some cases, it may not have significant impact on trends. It is important, however, that the presence and treatment of any bias is communicated to end users, to foster confidence in scheme outputs and ensure that data are adequately treated in further analyses or decision-making processes and are correctly interpreted. This need for transparency regarding data limitations is embedded in the UK Code of Practice for Statistics, which all producers of official statistics are expected to follow, which states: *“Relevant limitations arising from the methods and their application, including bias and uncertainty, should be identified and explained to users. An indication of their likely scale and the steps taken to reduce their impact on the statistics should be included in the explanation”* (UK Statistics Authority 2022).

2. Methods

A review was conducted of the contents of 26 documents relating to 6 UK recording schemes representing a variety of taxonomic groups (Table 1). These documents were accessed directly from the relevant scheme websites and therefore represent the publicly available summaries of scheme data. For scheme-specific methods and analyses, see the relevant references in Table 1.

Table 1. Recording schemes and documents reviewed for this report.

Scheme	Scheme Objective(s)	Reviewed document title / reference
UK Butterfly Monitoring Scheme (UKBMS)	Monitor changes in the abundance and status of UK butterflies	Annual reports 2019 & 2020
		The State of the UK's Butterflies 2015
		Summary of UKBMS data capture, processing, validation and reporting 2018
		UKBMS technical background document 2021
Wetland Bird Survey (WeBS)	Assess UK non-breeding waterbird population sizes and trends in distribution and abundance, in addition to assessing the importance of individual sites	Waterbirds in the UK 2018/19 & 2019/20 (Frost *et al.* 2020, 2021)
		Survey Methods, Analysis & Interpretation
		Guidance to interpretation of Wetland Bird Survey Alerts 2019
National Plant Monitoring Scheme (NPMS)	Use plant abundance and diversity to monitor changes in UK habitat quality and distribution	Pescott *et al.* 2019a
		Walker *et al.* 2015
		The potential uses of data from the National Plant Monitoring Scheme: A scoping report
		Pescott *et al.* 2019b
		NPMS Annual Report 2021
Breeding Bird Survey (BBS)	Monitor population changes of common UK breeding bird species	Burns *et al.* 2020
		The Breeding Bird Survey annual reports 2019 & 2020
		BBS methodology and survey design
Pollinator Monitoring Scheme (PoMS)	Monitor changes in UK insect pollinator populations	Pollinator Monitoring Scheme newsletter 2019
		UK Pollinator Monitoring and Research Partnership (PMRP) Progress Report October 2020
		UK Pollinator Monitoring and Research Partnership (PMRP) Progress Report January 2019
		Carvell *et al.* 2020c

Scheme	Scheme Objective(s)	Reviewed document title / reference
National Bat Monitoring Programme (NBMP)	Monitor changes in UK resident bat populations	Annual Reports 2019 & 2020
		The state of the UK's bats 2017
		The UK's National Bat Monitoring Programme Final Report 2001

This report adopted the four general bias domains defined in Boyd *et al.* (2022), namely geographic, environmental, taxonomic and "other potential biases" (Table 2). As in Boyd *et al.* (2022), within the first three domains we distinguish between bias in overall coverage and temporal changes in domain coverage. The final "other potential biases" category incorporates further sources of bias generalisable across the monitoring schemes, such as those relating to observer behaviour. These categories provide a clear framework for our assessment of the communication of bias and recommendations for improvements. There may be further scheme-specific biases that are relevant, and in some cases certain bias categories may not be fully independent (e.g. environmental biases may result from geographic biases, and misidentification of species may be linked to certain observer biases), but the chosen categories are considered suitable for the purpose of general comparison between schemes.

Table 2. Bias categories assessed in this report.

Bias Grouping	Bias description
Geographic	Non-random distribution or inadequate coverage of sampling effort/sites relative to UK geography
	Changing geographic distribution of effort/sites over time
Environmental	Non-random distribution or inadequate coverage of sampling effort/sites relative to UK bioclimatic variables or habitats
	Changing habitat coverage of effort/sites over time
Taxonomic	Inadequate sampling of species and non-random or inadequate spatial coverage
	Changing taxonomic coverage over time
Other	Under/over-sampling of individuals at a site
	Variation in the probability of detecting species/individuals
	Misidentification of species

Skew in the spatial coverage of sites and/or distribution of sampling effort or in coverage of habitats/environmental variables can produce trends which are not representative of changes across the wider UK and/or focal environmental domain and may artificially accentuate spatial patterns of variation in species richness (Isaac *et al.* 2014; Isaac & Pocock 2015). Such skew could occur within a structured scheme if recorder uptake is biased towards certain areas, such as near population centres or specific habitats. Temporal bias in geographic and environmental coverage may include changes in the distribution of sites or sampling effort over time. Such changes have the potential to inflate our estimates of population trends. For example, if the number of sites sampled increases each year, it is likely that resulting species population/distribution estimates will also increase relative to baseline conditions regardless of a lack of overall population/distribution change (Isaac & Pocock 2015). Similarly, if the sampling effort at each site is not constant, then changes in biodiversity at the site/habitat level may be missed or seasonal biases may be introduced (Isaac *et al.* 2014).

Some of the focal monitoring schemes produce indicators representing aggregate trends of a set of species (e.g. UKBMS, BBS). The omission of certain taxa due to insufficient data (e.g. rare or cryptic species, or those in under-sampled habitats) represents a taxonomic bias, though the extent to which this influences the overall results will depend on what the indicator purports to represent and whether other species with similar ecological functions are included. Spatial unevenness in coverage of different taxa (excluding that resulting from genuine differences in species distributions) may also introduce bias as trends occurring in one region may not be representative of those occurring in others. Temporal changes in the level of sampling effort for different species may also introduce bias into individual or aggregate trends, in much the same way as for the geographic or environmental domains.

Several factors relating to the actual sampling process could also introduce bias. Cryptic or rare species may be undetected during transects or other counts, resulting in their omission from data records. This is particularly true when sampling effort per visit varies, as the more time spent searching, the more species will be identified (Isaac & Pocock 2015). Recorders may also struggle to accurately count individuals, either due to large numbers being present or, in the case of very mobile species, due to repeated observations of the same individual. This could under- or over-represent population estimates, respectively. Finally, difficulties in correctly identifying species, due to the presence of extremely similar taxa and/or a lack of recorder experience, may also result in biased estimates of population size or distribution. These additional biases are likely to vary by recorder, and therefore will probably represent random variation in the underlying data rather than some major systematic scheme-wide bias. However, there is still the potential for these factors to result in broader bias, for example if improvement to recorder experience levels or technological advances result in better sampling of species over time. Further, site or species comparisons may be difficult when such observer variation is present, which is a factor which may be relevant to future studies that use scheme data.

During review of each document, it was noted whenever a potential bias was identified and recorded the context of the bias reporting (i.e. whether it was explicitly identified as a bias or implicitly referred to, and whether potential impact on outputs was discussed or mitigation measures suggested). In each case, the record was assigned to one of the above categories, allowing us to build an overview of how comprehensively the schemes report each potential bias. For the purposes of producing an overall summary of the reporting of bias across schemes, each scheme was given a score in each category, representing the extent to which the scheme documents identified and assessed bias within that category. The scores were “None” (no indication of bias presence), “Implicit” (no explicit reference to bias but enough information in text to make subjective inferences), “Explicit, unassessed” (potential for bias clearly identified but no assessment of impact), and “Explicit, assessed” (bias clearly identified and assessment of impact provided). A differentiation is made between the complete absence of any description of a given bias and the provision of implicit information regarding coverage of the bias domain, as this gives an indication of the degree to which end users will be able to determine the potential for bias in the data. However, in the absence of clear evidence that targeted analysis of potential bias has been carried out, a conservative approach to interpretation would be to assume that there is a high risk of bias present within that domain. It is therefore vital that schemes provide a clear assessment of each domain to provide confidence in results.

3. Results and discussion

3.1. Overview

Information regarding bias is generally dispersed widely across and within scheme documents. This often requires the reader to determine (subjectively and without statistical basis) the presence and severity of bias through exhaustive review of multiple documents. The content of different documents reflects their intended audience so the extent and detail with which biases are reported will vary, however the lack of a single comprehensive summary reduces the accessibility of this information to end users and other stakeholders, which may lead to either uncertainty or false confidence in the robustness of outputs.

A comprehensive overview of the presence and scale of different biases, and their mitigation, should be provided alongside the annual reports and other publications. There are already some basic examples of this in the scheme documents: the NBMP annual reports include a section on the robustness of monitoring data, which covers some of the potential biases within each survey; the WeBS Survey Methods, Analysis & Interpretation document includes sections describing some of the factors which may influence data representativeness for each trend/index type; the NPMS Technical Review provides a section on quality assurance and sources of error and bias. These sections could however be expanded to give information regarding issues relating to wider scheme design or coverage, be it spatial or temporal, and to provide explicit assessment of the impact of these biases. The final format could either be a section within technical reports or represent a standalone document. For example, it might be sufficient to publish a completed assessment of bias conducted using the ROBITT tool (Boyd *et al.* 2022) as this provides a clear overview of each bias category and provides a standardised framework for bias reporting, facilitating comparison of the extent of bias in schemes (Box 1). The relative importance of different bias domains for trend robustness may vary by scheme depending on their underlying design and objectives, and this will be an aspect that should be communicated in the bias assessment where possible.

Where biases are identified there is also often no assessment of their likely impact on trends and little information regarding their mitigation. When analytical mitigation measures are identified they are often vague, such as a statement that a given bias is “taken into account during analyses”. This makes it difficult for the reader to clearly understand the extent to which the bias has been mitigated. A clear commitment of the UK Code of Practice for Statistics is that the steps taken to reduce the impact of bias or uncertainty should be explained to end-users (UK Statistics Authority 2022), therefore it is important that a detailed overview is provided of any implemented or potential mitigation measures. The clear identification of currently implemented or potential mitigation measures within each bias domain will also help target further scheme research priorities. Again, this information could be included in a bias assessment, as is already required by the ROBITT framework (Box 1).

Box 1: The suitability of the ROBITT framework for reporting bias in UK monitoring scheme data

The ROBITT tool (Boyd *et al.* 2022) encompasses a set of questions designed to extract information regarding potential biases within studies, with the purpose of preventing researchers from making inferences that aren't supported by their data. The tool was initially designed to encourage researchers to ensure the representativeness of their results when using large and often opportunistic species distribution and abundance datasets aggregated from multiple sources. The constituent signalling questions may however be just as applicable to well-established structured monitoring schemes.

A first step of the ROBITT framework is to define the geographic, environmental, temporal and taxonomic domain of interest. This will be particularly important for schemes that provide both UK and constituent national trends, as these bias assessments will need to be conducted at both the UK and individual country levels given that the degree of bias within each domain may vary depending on the scale of interest. The ROBITT framework then asks three questions applicable to these geographic, environmental and taxonomic domains:

1) The first question pertains to the overall representativeness of the data relative to the boundaries of the intended analyses. As in Boyd *et al.* (2022), this could be addressed by providing figures that display coverage relative to the wider domain of interest (e.g. testing the distribution of sampling sites relative to an expected random distribution or using ordination to represent environmental coverage of sites relative to overall bioclimatic or habitat variables). The use of figures or statistical tests will provide a more transparent and objective demonstration of the presence and severity of bias than the current use of general and unevidenced statements found in many of the scheme documents.

2) The second question investigates whether there are changes in the coverage of the focal domain over time. Addressing these questions using analytical means (e.g. by testing the distribution of sampling sites relative to an expected random distribution, or by comparing the environmental space or species composition represented by samples in each time period) will provide a clear and unambiguous overview of the presence and severity of this bias in each domain.

3) The third question then requires an explanation of the mitigation measures which are implemented to account for the identified biases. We recommend that these measures are comprehensively described to ensure that other end users of the data can replicate them. In situations where bias is identified but not considered to have significant implications for trends, this section should be used to clearly communicate this. Additionally, there may be situations where a bias is present but cannot be mitigated – this section again provides an opportunity for this to be identified and for a description of the resulting caveats in trends to be stated.

Finally, the ROBITT framework provides an opportunity for "other potential biases" to be discussed. This will provide an opportunity for the presence of further biases to be communicated, which in the context of monitoring schemes will most likely relate to observer behaviour or experience. In most cases these are unlikely to represent systematic biases, but it will still be important they are clearly communicated to end users who may have a variety of objectives.

3.2. Reporting of bias in each domain

There is variation in the extent to which bias is identified and assessed, both between bias domains and schemes, with some domains reasonably well identified and others lacking any discussion (Figure 1).

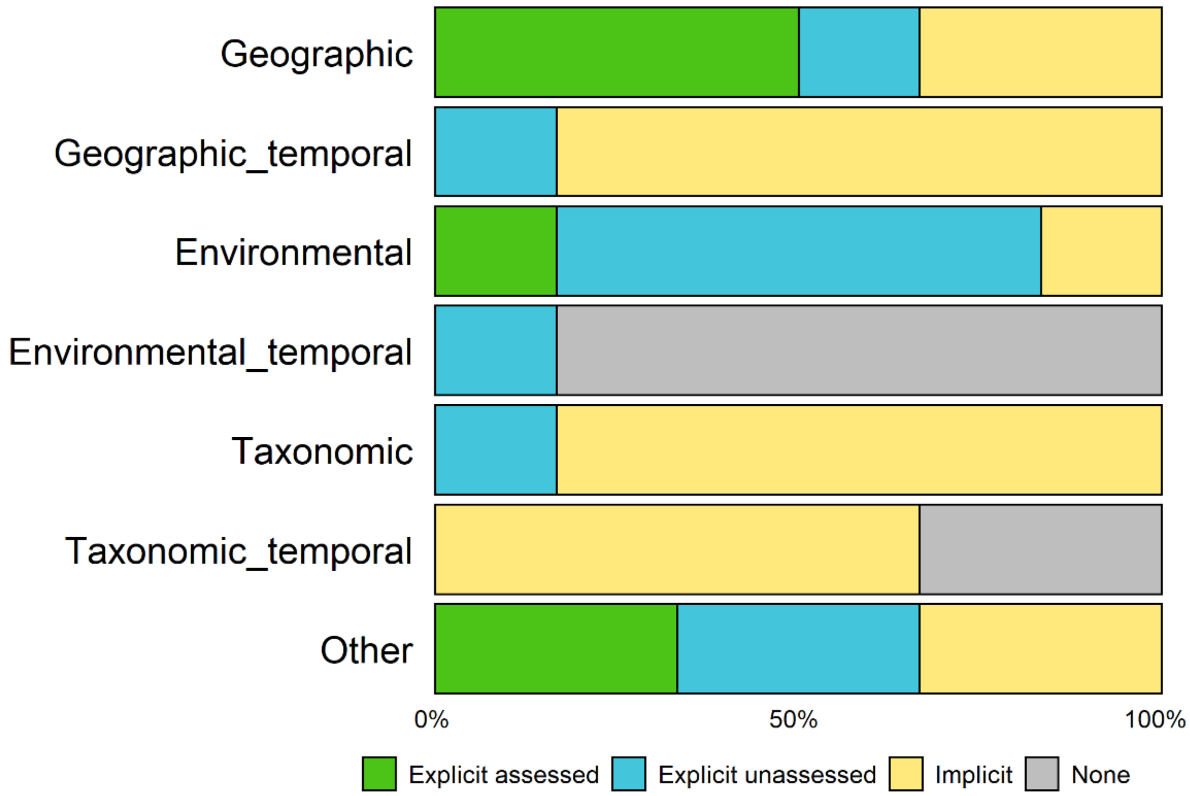

Figure 1 Overview of the proportion of schemes reporting bias falling under the domains of geography, environment, taxonomy and other potential biases (primarily observer). Colours indicate the level of detail provided across scheme documents regarding the presence and impact of bias (see plot legend).

3.2.1. Geographic bias

Geographic coverage is generally well identified, with four of the six schemes explicitly discussing this domain in terms of bias, generally relating to the random stratification of sites relative to population density. Three schemes also provide an assessment of the potential impact of this bias on trends. Mitigation measures identified in some schemes include the imputation of missing data using information from other sites, weeks and years (UKBMS) and the use of weights by proportion of area sampled (BBS and NBMP).

Temporal change in geographic coverage is quite under-reported. All schemes provide some overview of the number of sites sampled, generally in their annual reports, but the temporal extent of this reporting in any given document varies; in most cases only the number of sites sampled during the relevant year or the change in number of sites relative to the previous year is reported, with no description of whether this represents a significant bias. Only one scheme (BBS) provides a breakdown of the number of sites sampled in each year and UK region, which is valuable for region-specific bias assessments. There is no evidence of assessment of the severity of temporal biases in geographic coverage and implications for trends across schemes.

3.2.2. Environmental bias

Most schemes explicitly identify environmental bias, though few provide any assessment of this. Environmental bias is generally considered in terms of broad habitat types, with little assessment of coverage relative to other environmental datasets such as bioclimatic gradients. The potential for habitat biases to be present is explicitly identified in five of the six schemes, but most simply provide a general statement about certain habitats being under- or over-represented. Only one scheme (NPMS) provides an explicit assessment of the distribution of allocated and surveyed sites in environmental space (both bioclimatic and habitat) relative to that of all released sites, allowing clear conclusions to be drawn regarding the severity of bias. Additionally, only one scheme (WeBS) provides a description of a mitigation measure implemented for dealing with differences in habitat coverage between sites. There is a clear need for further assessment of how environmental biases may influence species trends, and how they can be mitigated.

Temporal biases relating to environmental coverage are generally not discussed, despite the fact that changes in the distribution of sampling effort between and within years could result in variability in the coverage of environmental variables. Efforts should be made to identify temporal changes in environmental coverage of sampling, and there should be an assessment of how severely these changes influence trend estimates. Additionally, any potential analytical mitigation measures should be discussed.

3.2.3. Taxonomic bias

All schemes provide some information regarding the taxonomic coverage of trends, but this is largely limited to the number of species sampled sufficiently for inclusion in trend calculation. Only one scheme (UKBMS) directly provides any indication of what proportion of species present in each UK region are sufficiently sampled, which is important information for determining whether bias is present. Additionally, only one scheme (NPMS) explicitly assesses the representativeness of taxonomic coverage, while others only provide an implicit indication of the effect of taxonomic bias on trends, such as by identifying non-comparability of indicators between UK nations due to differences in taxonomic composition.

There is a lack of discussion regarding temporal bias in taxonomic coverage. Some schemes provide a breakdown of the temporal coverage of each species/group but there is no assessment of potential bias resulting from variation in trend taxonomic composition. Only one scheme (PoMS) provides any indication that increases in the number of species sampled could bias trends, though no discussion is provided regarding how the trends are impacted. In some schemes, it may be that most key species are now sampled sufficiently each year and there is therefore little variation in taxonomic coverage. Increases in sampling effort over time will almost certainly drive an increase in the number of species meeting thresholds for inclusion in analyses, and greater sample sizes will improve the reliability of trend estimates. Temporal biases in taxonomic sampling effort are therefore likely to be present in all schemes, though for long-established schemes these may only be an issue for earlier time periods. Regardless, it is important that the potential for such changes to bias long- and short-term trends is assessed and that any possible mitigation measures are reported.

3.2.4. Other potential bias

The reporting of other potential sources of bias is inconsistent across schemes. The potential for over- or under-sampling is clearly identified in some schemes (e.g. WeBS, NPMS, NBMP) but absent from others. In contrast, the issue of non-detections is clearly identified in most schemes though generally not assessed. The probability of non-detections will vary based on the methods employed by each scheme and by taxa. For example, PoMS utilises both small scale (50 cm^2) FIT counts which should be easily monitored and pan traps which may be less biased in their sampling of taxa than transects (Templ at al., 2019). However, there may still be some species which are infrequently detected, either due to small size or inconspicuous morphology or because they aren't attracted to pan traps. Other schemes such as BBS and WeBS which survey species over large areas/transects in complex habitats and utilise visual or vocal cues for detection may be particularly susceptible to detection biases, including those resulting from recorder experience and abilities. Such biases may however be mitigated during analyses (e.g. by inclusion of specific model covariates relating to detection probability). Similarly, the probability of misidentifications may vary between schemes based on the methods and taxa sampled, and the potential for this bias is only variably assessed. It is important to note that these biases will primarily add to variance in the underlying data, which is unlikely to have a significant impact on the ability to detect trends. However, they may still affect comparisons between sites and species, particularly when volunteer turnover occurs, and could result in systematic bias if they display unidirectionality across sites/recorders. It is therefore important that the presence and magnitude of such biases is clearly communicated, and an overview of mitigation measures is provided.

4. Conclusion and recommendations

This report reviewed how bias pertaining to various domains is communicated in published UK monitoring scheme documents. Overall, there is a need for more explicit identification and assessment of all bias domains, but particularly those relating to taxonomic coverage, representation of bioclimatic gradients, and temporal change in coverage within all bias domains. A key priority for all schemes should be the communication of bias assessments in a standardised and accessible format.

4.1. Recommendations

- A key priority should be the development of a standard format for displaying the results of the bias assessments alongside scheme publications (e.g. by adapting the ROBITT framework), to improve end-user and stakeholder confidence in data and trends.
- There is a need for clearer identification and assessment of bias domains, particularly those relating to taxonomic coverage and temporal changes within all domains.
- Extending the assessment of environmental bias in each scheme to include major bioclimatic gradients will improve understanding of scheme capacity to detect population trends in relation to large-scale climatic variation.

Clearer identification of implemented and/or potential mitigation measures for each bias domain will improve confidence in results and help focus further scheme research priorities.

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Weblinks

Table 3. Full URLS for weblinks used in the text.

Weblink text	Full URL
Methodology and survey design	https://www.bto.org/our-science/projects/bbs/research-conservation/methodology

Acronyms

Table 4. Explanation of acronyms used in the report.

Term	**Definition**
BBS	Breeding Bird Survey
FIT	Flower-Insect Timed
NBMP	National Bat Monitoring Programme
NPMS	National Plant Monitoring Scheme
PoMS	Pollinator Monitoring Scheme
ROBITT	Risk-Of-Bias In studies of Temporal Trends in ecology
UKBMS	United Kingdom Butterfly Monitoring Scheme
WeBS	Wetland Bird Survey