The hidden structure of unstructured citizen science insect monitoring

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Abstract

Insects are vastly under-represented in biodiversity monitoring, leading to uncertainties about their trends. Semi-structured monitoring, relying on protocol reporting than protocol standardization, has emerged as a promising and more flexible alternative to structured monitoring, retaining broad participation. We examined the potential opportunities and barriers for semi-structured monitoring of insects, using dragonfly monitoring in the UK as a case study. We found that many insect recorders already follow attributes of structured surveying, reporting complete species lists, collecting abundance data and revisiting the same sites. Most are also willing to report more comprehensive metadata, such as survey effort, but only a subset would follow a fully standardised protocol. We outline the key ecological and modelling opportunities if semi-structured monitoring were enhanced, but also identify the specific challenges for insects. Our findings highlight the overlooked structure within citizen science monitoring data that could be leveraged for more robust analyses of insect biodiversity change.

Keywords: biodiversity monitoring; Humbolt extension; semi-structured recording; survey protocols

Introduction

Citizen scientists make enormous contributions to biodiversity (Chandler et al. 2017), documenting long-term terms (Outhwaite et al. 2020); mapping distributions (Johnston et al. 2020), and identifying drivers of change (Mandeville et al. 2023, Woodcock et al. 2016). Given these successes, citizen science could play a central role in meeting the data needs of the Kunming-Montreal Global Biodiversity Framework and other national and international conservation policies (Danielsen et al. 2024, Fritz et al. 2019). However, citizen science data is diverse — projects vary in design, attract participants with varying motivations and skills, and rely on a mix of platforms for data submission (Pocock M. J. et al. 2017). This diversity raises concerns about data quality in aggregate databases (Arazy and Malkinson 2021, Della Rocca et al. 2024, Dobson et al. 2020), leading to questions about the best way to improve its value (Callaghan et al. 2021).

One of the main dimensions along which citizen science schemes vary is the degree of sampling structure (Kelling et al. 2019). Structured schemes employ a standardized protocol specifying how, when, and where participants collect data, often on species abundances, aiming to minimize sampling variation and bias for robust trend assessments. Unstructured schemes aggregate species occurrence data from opportunistic observations and independent surveys leading to data collected using a variety of methods (Arazy and Malkinson 2021, Bowler et al. 2022, Della Rocca et al. 2024). Across schemes, the degree of structure in the protocol is often negatively associated with the level of participation (Didham et al. 2020, Isaac and Pocock 2015, Kelling et al. 2019, Pocock M. J. et al. 2017). Highly structured schemes attract fewer participants due to reduced flexibility of the sampling protocol and higher prerequisites in species identification or ecological survey skills. However, structured schemes yield the most robust analyses; although various solutions have been proposed to make use of unstructured data (Isaac et al. 2014, Shirey et al. 2023).

For most insect taxa, in most countries, structured schemes have not yet developed, or participation is expected to be too small to be feasible (Pocock M. J. O. et al. 2015). Nonetheless, insect trends have been in the spotlight during recent years, spurred by reports of strong declines within local time-series (Hallmann et al. 2017, van Klink et al. 2020). Assessments of large-scale species trends of insects are typically based on citizen science (Outhwaite et al. 2020, Zylstra et al. 2021), using unstructured data, or data treated as unstructured (Bowler et al. 2022, Fajgenblat et al. 2025, Outhwaite et al. 2020). Consequently, these trend estimates are often accompanied by caveats regarding their robustness. Strategies are needed to improve the quantity and quality of insect monitoring data to improve trend assessment.

Semi-structured recording potentially offers a “sweet spot” between unstructured and structured recording (Arazy and Malkinson 2021, Kelling et al. 2019, Welvaert and Caley 2016), which could be particularly useful for insect monitoring. In semi-structured monitoring, recorders are free to decide how, when and where they record, but they collect and report details of the protocol as metadata (e.g., type of survey, time surveyed and so on) along with the species’ observations (Broughton and Pocock 2022, Kelling et al. 2019). Semi-structured recording is attractive because it offers flexibility in monitoring decisions, retaining high participation, whilst the reported metadata allow direct modelling of the sampling variability (Dobson et al. 2020). Semi-structured data therefore allow for more robust assessments of change, and potentially a greater range of questions, than using only unstructured data (Guillera-Arroita et al. 2015). Semi-structured schemes have been highly successful in engaging large numbers of participants with bird monitoring, in which apps like eBird (international) or BirdTrack (in the UK) with fields for complete list reporting and recording effort, e.g. distance travelled and time spent (Kelling et al. 201), generating information about species distributions and trends (Johnston et al. 2021, Johnston et al. 2025); but see (Boersch-Supan et al. 2019, Neate-Clegg et al. 2020).

Semi-structured recording platforms for insects could offer various options for reporting metadata, each entailing different costs and benefits for citizen scientists and data analysts (Fig. 1). For instance, options could include information about the survey (e.g. survey protocol, completeness of species list, and survey effort); information about the specific species observation (e.g., number of individuals; life stage observed; behaviour that might indicate breeding habitat, or other species interactions), and other contextual survey information (e.g. weather, habitat). Moreover, recent extensions to species observation metadata standards, via the Humboldt extension for Ecological Inventories to DarwinCore (Guralnick et al., 2018), ratified in 2024, provide a timely set of metadata standards that could increase the consistency of metadata reporting from semi-structured insect recording.

Here, we assess the opportunities for semi-structured monitoring of insects among citizen scientists, using dragonfly (hereafter referring to both dragonflies and damselflies) monitoring in the UK as a case study. Dragonflies are a relevant group since they are targeted by a broad range of citizen scientists, both expert and causal recorders, and are monitored by a diversity of methods via multiple platforms. We first review existing platforms to assess which metadata can be reported to capture semi-structured monitoring. We then discuss the findings of a questionnaire disseminated to recorders that sought to understand choices about reporting platforms as well as current monitoring practices and perspectives on possible future practices. We draw together our findings to highlight the often-overlooked parallels between current recording practices and the typical attributes of semi-structured or structured monitoring as well to identify the opportunities that would arise if semi-structured monitoring of insects was enhanced.

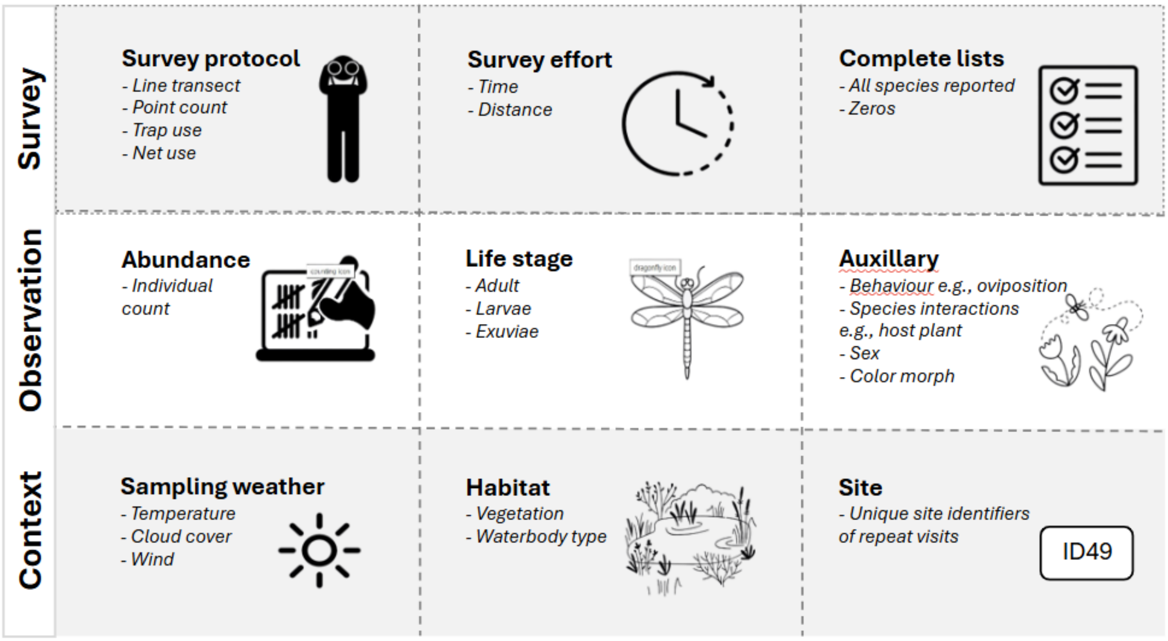

Fig 1. Potential attributes that can be reported as metadata for semi-structured monitoring of insects, including survey-level attributes; observation-level attributes and contextual attributes. Icons from the noun project (left to right: G. Khoon Lay; L. Carvalho; B. Ulum; L. G. Al Achmad; Pixel X; Softscape; lailistudio; Softscape).

Review of reporting platforms

We first mapped the types of metadata associated with species observations that are collected by the most popular reporting platforms for dragonfly monitoring in the UK. To do this, we downloaded dragonfly occurrence records from GBIF for the UK between 2010 and 2024 and summarised the number of records per publisher/collection code. We focused our subsequent assessment on the platforms with the most records. For each platform, we visited the website or smartphone app and extracted information on the metadata that can be provided with each species observation, along with the form of data (e.g., free text or categorical) and any options/restrictions on how data could be supplied.

We found that the most common platforms were a UK focused platform (iRecord), regional platforms (NatureSpot [for Leicestershire and Rutland], Southeast Wales and Bristol), international platforms (iNaturalist, Observation.org) and UK platforms primarily targeting other taxa (BirdTrack [birds]; UKBMS [UK Butterfly Monitoring Scheme, butterflies]). These platforms varied in how much additional metadata they collect beyond the core metadata of species, date and location of observation (Fig. 1). Information on the abundance of observed species was the most common additional form of metadata possible to report; however, platforms varied in how it could be reported (as an exact count or as an interval from a set of options). The next most common metadata types were life stage of the observed individuals and habitat. List completeness (i.e., whether all detected dragonfly species were reported) was collected by almost half of the platforms, usually via a simple checkbox. The rarest metadata types collected were survey protocol, duration and weather, with these data primarily collected on apps/websites in which dragonflies are recorded as by-catch observations (e.g., UKBMS and BirdTrack). While iNaturalist does allow some reporting of additional metadata as optional observation fields, they are user-defined and hence not harmonised. None of the platforms allow the reporting of surveys in which no dragonflies were seen (‘zero surveys’).

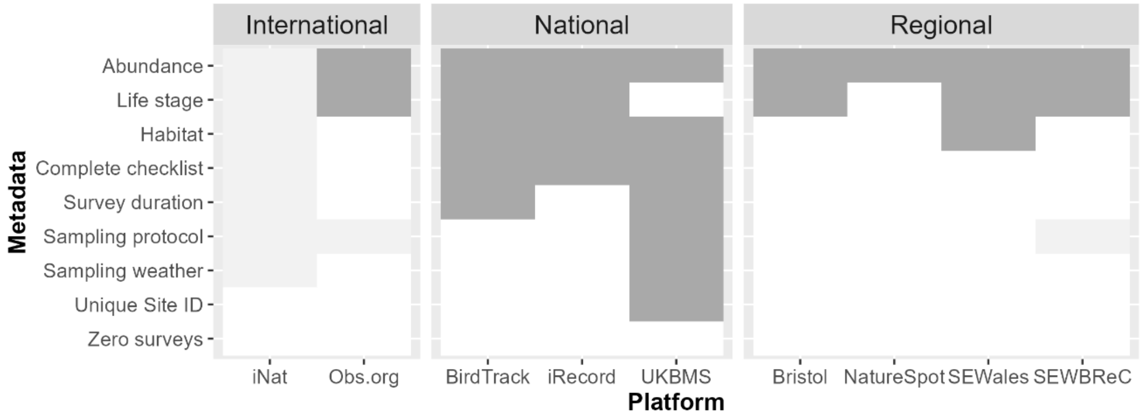

Fig. 1 The most common types of metadata associated with each species observation, as collected by the most popular dragonfly data reporting platforms (based on number of records in GBIF). Dark grey = metadata is a main field. Light grey = metadata is possible, but it is not a field on the main recording form. For iRecord, we assessed the dragonfly-specific website forms. We note that in some cases (e.g., UKBMS), the protocol is set by the scheme design and does not need to be entered by recorders during observation submission. iNaturalist and Observation.org are abbreviated to iNat and Obs.org.

Questionnaire on recording and reporting

Our questionnaire aimed to understand how recorders collect and report data and opportunities and barriers to promote more structured monitoring (Appendix S1). The cover page of the questionnaire explained the purpose and use of the questionnaire results and clarified that the intended target audience included beginner and expert recorders, as well as specialist and generalist recorders. The questionnaire was approved by the UKCEH Human Research Ethics committee, and we included a checkbox for informed consent. We piloted the questionnaire with c. 10 collaborators involved in species recording to refine the questions. The final questionnaire was distributed using Jisc Online Surveys. Apart from the consent box, we allowed all questions to be optional, leading to slight differences in the number of answers per question. We disseminated the questionnaire via the main organisations involved in UK dragonfly recording, via social media of the British Dragonfly Society (BDS); BirdTrack; Butterfly Conservation, and the email list of iRecord users who submitted at least five dragonfly observations in the previous year. The questionnaire was opened between 6th September and 15th October 2024, so that the questions could be answered with respect to recent monitoring activities during the main dragonfly flight period.

Questionnaire participants

In total, 610 recorders completed the questionnaire, with a mode age group of 65 or older and 73% male, and with almost all of white ethnic origin (99%) (Fig. S1). Recorders had typically been involved in dragonfly monitoring for more than 10 years (32% of respondents) and were active around once a week during the adult flight season (42%) (Fig. S2). Most (67%) were confident in their species ID skills, at least for most species in their local area (Fig. S3; see Table S1 for common problems). However, a substantial number of recorders were newer to dragonfly monitoring (<2 years) and recorded infrequently (monthly or less), indicating that our results do not solely represent the keenest enthusiasts.

Platform preferences

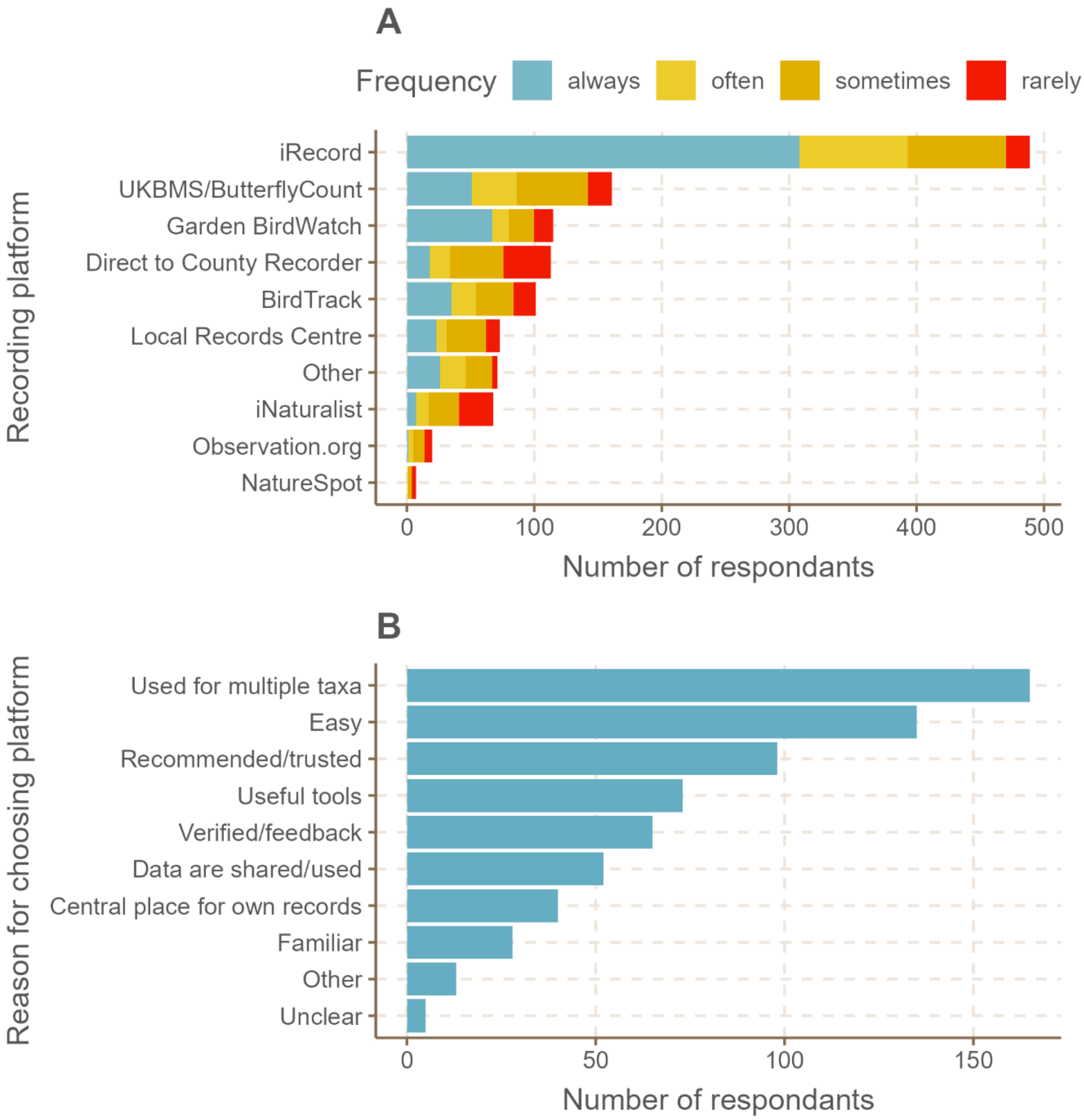

Fig. 2 A: **Number of recorders using different platforms for submitting dragonfly observations**. 'Other' included: Facebook, Living Record, Mapmate, Obsidentify, Local groups, Adnoto, WhatsApp, iSpot, Seek. B: Summary of the content analysis to identify the common themes of the reasons given for choosing a specific platform (see Table S2 for more details).

iRecord – the platform recommended by the British Dragonfly Society – was found to be the most popular platform according to the questionnaire respondents (Fig. 2A). While this result may have been partly affected by our questionnaire dissemination channels, this finding was consistent with the share of iRecord records within the GBIF data download (57% of records mentioned iRecord in the collection code). Around half of the recorders used multiple platforms (49% selected more than one that was used at least ‘sometimes’). Reasons given for their preferred platform (Fig. 2B, Table S2) included the ability to record multiple taxa; its ease of use (flexibility, convenience and speed); its recommendation/trustworthiness (being used or suggested by others); the tools available by the platform (e.g., tools for species identification or recording location; ability to download or upload records; ability to use or develop tailored forms or projects for recording); receiving feedback (including verification of their observations), and knowledge that their data was being shared and used for science and conservation (Table S2).

Observation and survey types

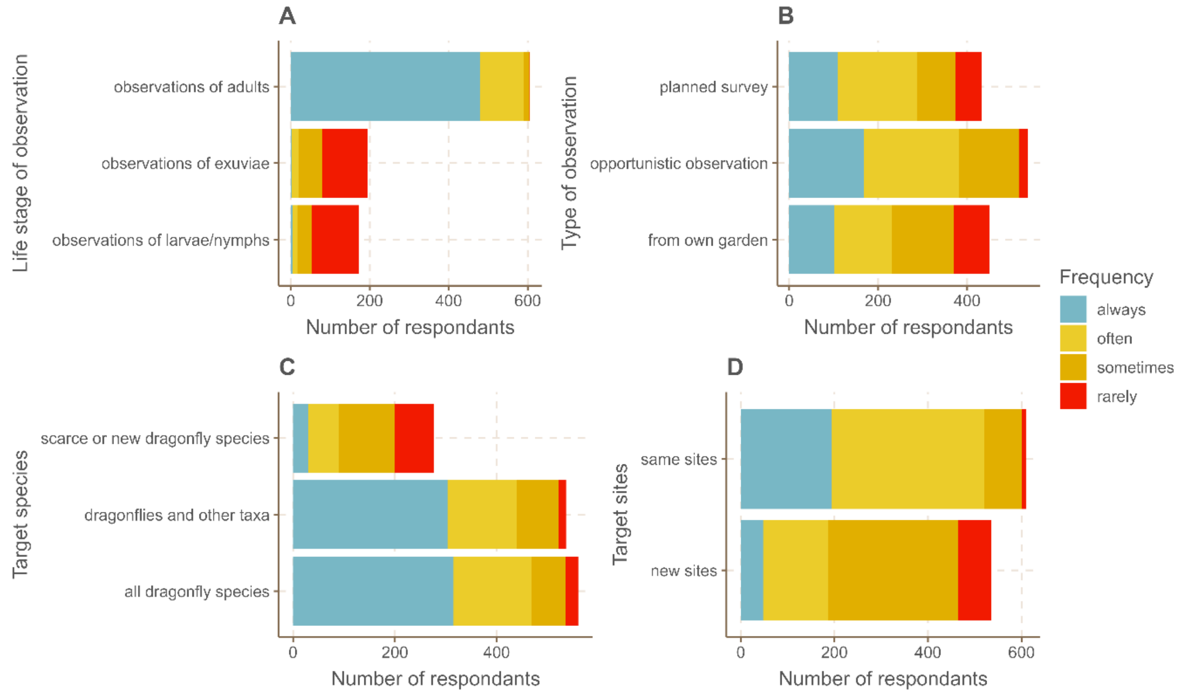

Fig. 3 Number of recorders submitting specific observation and survey types. A: data on specific life stages (adults, larvae, exuviae); B: observation type (going to a place for a planned survey; opportunistic observation while doing other things; observations from home garden); C: target species group during a survey (only new/scarce dragonfly species; all dragonfly species; dragonflies and other taxa) and D: target sites (revisiting the same sites or going to new sites).

Most recorders (79%) focused 'always' on observations of the adult life stage and 'rarely' or 'never' reported observations of larvae or exuviae (72%) (Fig. 3A). Also, most recorders 'always' or 'often' reported all the dragonfly species that were detected i.e., complete dragonfly lists (77%), as well as reporting other taxa, beyond dragonflies, at the same time (72%) (Fig. 3B). Relatively few respondents focused on only reporting scarce dragonfly species (15% 'often' or 'always'). Survey types were highly variable, within and across respondents (Fig. 3C). The questionnaire distinguished between planned surveys at specific sites; opportunistic observations and surveys made at home garden ponds. Many (42%) respondents use multiple survey types, but 47% 'often' or 'always' performed a planned survey (Fig. 3C). Also, 85% 'often' or 'always' repeatedly visited the same site or sites for recording (Fig. 3D).

Current and future monitoring practices

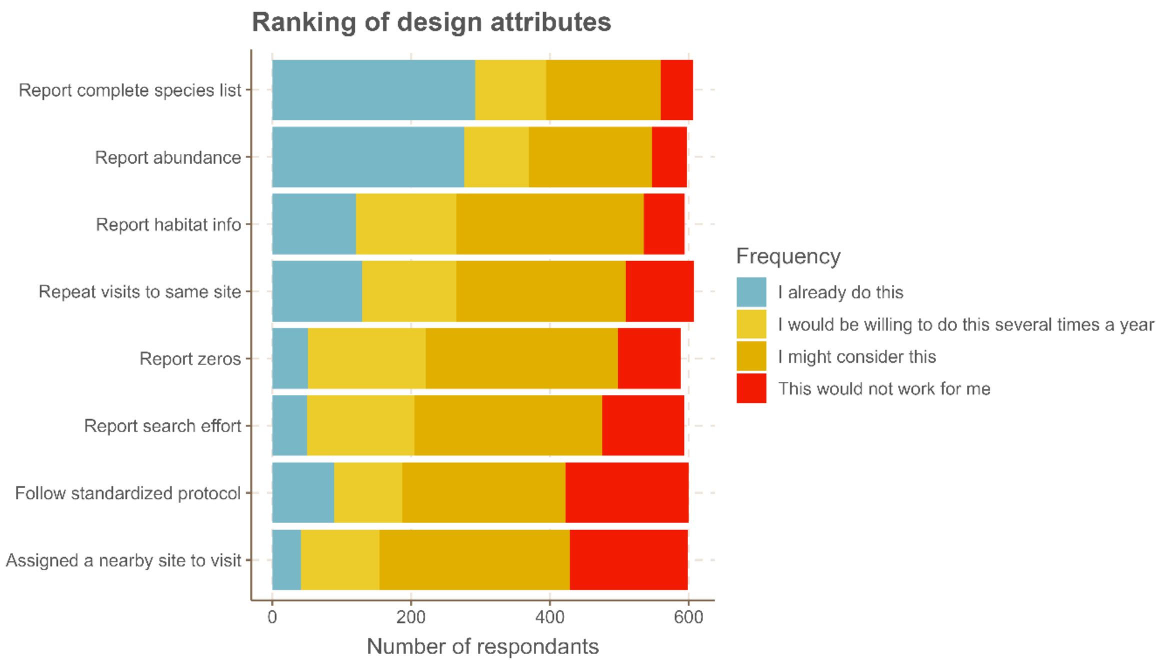

Fig. 4 Opinions of recorders regarding design attributes of semi-structured recording. For each attribute, the respondents selected one of the four possible answers.

In terms of current practices, the design attributes already common among dragonfly recorders include collecting complete lists (Fig. 3c and Fig. 4) along with abundance information (Fig. 4). The most common attributes that respondents were most willing to include as part of the future effort, if not already part of their practice, include reporting zero surveys (i.e., when no individuals or any species were seen) and search effort (Fig. 4), confirmed by over 150 respondents (over 25%). Respondents were more divided in the appeal of other attributes: for instance, while 15% of respondents reported to already follow a standardized protocol (at least some of the time), another 29% reported that a standardized protocol would not work for them (Fig. 4). Indeed, a standardized protocol was the top feature that 'would not work' for most respondents. Being assigned a site to visit, usually near to their home, was also similarly conflicted with 28% confirming it 'would not work' while 45% 'would consider it' (Fig. 4). The main challenges to more structured recording were other monitoring priorities, including already being involved in the monitoring of other taxa, along with personal constraints, including both time constraints and access to dragonfly habitat (Table 3).

Table 3 General themes coded from responses to the open question about the design attributes of structured monitoring reflecting some of the challenges and opportunities

	Theme	**Specific components**
Challenges	Other monitoring priorities	- Too busy with existing dragonfly monitoring - Reluctance to change personal sampling protocol - Other focal taxa and schemes - Other monitoring objectives (e.g., atlas mapping rather than trend assessment) - Dependence on suitable weather conditions limits possibility to participate in multiple schemes
	Personal barriers / time-constraints	- Life is busy enough - Only opportunistic sampling fits with lifestyle - Health issues prevent further involvement
	Limited by access / distance	- Lack of transport to suitable monitoring sites - Long distance from home to suitable waterbodies - Prefer to focus on home garden surveys - Access issues to private land
Opportunities	Guidance / training	- Requests for more training or guidance e.g., identifying exuviae, or novel range-shifting species, or best sampling protocol
	Photography	- Photography as a motivation for wildlife recording - Photography as an essential part of species ID - Photography as a prerequisite for the downstream verification of a record
	Co-location	- Co-location of dragonfly monitoring with other taxa surveys would help - Consideration of whether to share location or also time of surveys when co-locating monitoring across multiple groups
	Better tools	- Current activities constrained by existing tools e.g., flagging repeat surveys, or add details of survey protocol, or entering 'zero' surveys

Synthesis

Apart from a few well-recorded groups in a few well-recorded countries, the long-term trends of most insects remain unknown. This is largely a reflection of their underrepresentation in large-scale structured biodiversity monitoring and the challenge of using sparse, opportunistic and unstructured citizen science data to calculate trends. Our findings indicate that there is great untapped potential in semi-structured monitoring as a flexible but information-rich approach to insect monitoring by citizen scientists. In fact, semi-structured recording is already 'hidden' within unstructured datasets, obscured by inconsistent reporting of the metadata. The newly-ratified Humbolt Extension to the DarwinCore standard for biodiversity records provides a timely opportunity to leverage the metadata that could be associated with semi-structured recording (Guralnick et al. 2018, Ingenloff et al. 2025). We outline below the key opportunities of semi-structured recording for more sophisticated modelling of the data and the wider range of ecological questions that can be addressed by semi-structured recording, but also the challenges of applying it to insects (Fig. 5). We hope our findings will encourage similar discussions of the potential for semi-structured insect recording in other regions and across a range of insect taxa, helping to track long-term trends and inform conservation efforts.

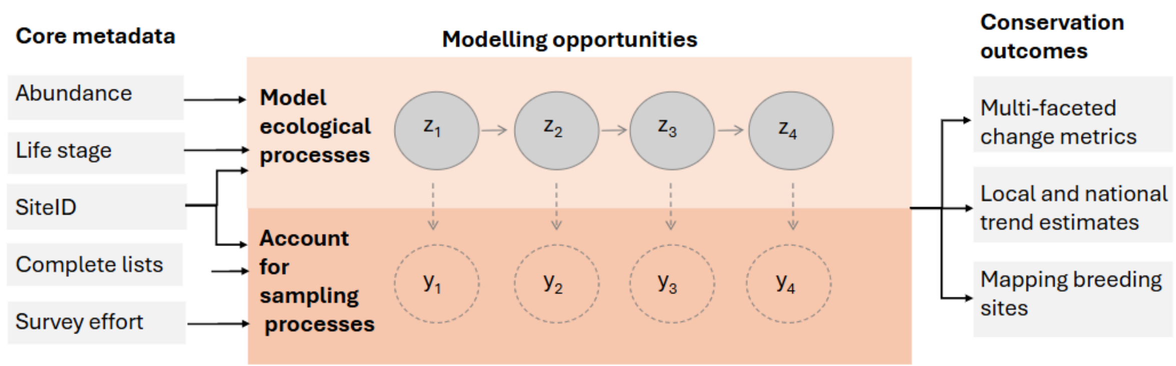

Fig. 5 Ability of metadata to expand the ability to ask ecological questions about insect dynamics (true state represented by z in different years) and model sampling variability (observation represented by y, collected in different years).

Ecological modelling with semi-structured data

Regardless of the ecological question, a core advantage of semi-structured monitoring is the enhanced ability to account for sampling variability and isolate the ecological patterns of interest. Metadata on list completeness help overcome one of the major sampling problems of unstructured data: the lack of absence reporting. The lack of absences in a dataset means that the lack of a species record in a time or place could either be due to no survey taking place, or a survey taking place but the species not being detected. With unstructured data, absences are often inferred using the target group background method (Chauvier et al. 2021) but this is not always appropriate since it requires assumptions about the sampling target i.e., which species would be reported if they were detected (Shirey et al. 2023). If metadata on list completeness was available, then it could be included for a more refined and robust approach to defining absences, which has improved model performance in other applications (Johnston et al. 2021). Most dragonfly recorders in our study already report complete lists or would be willing to do so, indicating the potential to collect these metadata, as is already widely done in bird recording using tools like eBird. However, despite the interest in complete list reporting, opportunistic records are likely to remain an important source of data. New developments in integrated distribution modelling (Isaac et al. 2020) could be used to integrate presence-only (opportunistic) and presence-absence (complete list) data streams, with the metadata allowing separation of these data streams.

Metadata on list completeness would not solve all absence-related issues. Another type of absence that is currently missing from unstructured data is complete absences - when no individual of any species within the broad target group was seen, and hence there was no species list reported at all. Didham et al. (2020) called this ‘the missing zero effect’, highlighting how it may bias region-wide trend estimates since colonisations are more likely to pass by undocumented [see also (Dambly et al. 2021)]. Nonetheless, many recorders answering our questionnaire indicated their willingness to report zero surveys and such surveys can be reported in typical structured schemes by a simple checkbox. Using the target group background method, zeros are only inferred if at least one species is reported, which means that the composition and size of communities affect the performance of this method (Botella et al. 2020). Absences are less likely to be inferred for species that less frequently co-occur with other species, for instance those flying early and late in the year or those inhabiting species-poor habitats, as well as for less species-rich taxon groups, such as dragonflies. Zero surveys can, however, arise due to different causes that vary in their importance. Zero surveys when conditions are suitable (including sampling weather and habitat) will be more important to record than zero surveys when conditions are unsuitable, supporting the collection of contextual information of surveys.

Survey effort, such as time spent recording and/or area covered, generates variation in the observations of different surveys, which might obscure patterns of interest if not accounted for in the analysis (Dobson et al. 2020, Kotze et al. 2012). Survey effort is only collected by a few platforms, but many recorders were willing to report it along with their species observations. A complication for using effort metadata is that the relationship between effort and observation will depend on the survey type. For dragonflies, longer surveys will increase the detection probability of exuviae, which require searching for, whereas adult dragonflies are often conspicuous with males patrolling a spatially-discrete territory, so their detection is more affected by area covered than survey duration. Hence, survey effort metadata is most useful when it is reported alongside the survey approach of planned surveys. Technology is transforming insect citizen science (Sheard et al. 2024) and can help to automate the collection of effort metadata e.g. tracking distance covered and time spent recording by a smartphone app.

Refining the ecological questions

In addition to improving the ability to model the data, semi-structured data may expand the breadth of ecological questions we can ask of it. We identity opportunities according to three main metadata types: abundance, site identifiers and life stage.

Abundance data typically contain more information on species' spatio-temporal dynamics than occurrence data. For instance, abundance data from semi-structured platforms such as eBird have revealed the nuanced ways that bird species' populations are changing (Johnston et al. 2025). As shown by our survey, many dragonfly recorders collect abundance data; however, analyses of the data often discard any available abundance information and instead focus on trends in occurrence (see 'challenges' section below for reasons). Abundance and occupancy trends are both relevant for understanding insect change because they are shaped by different processes; for instance, as shown by increasing distribution but declining abundance in moths (Dennis et al. 2019). Occupancy trends are also likely to have reduced power to document changes in the abundance of common and widespread species (which usually show high occupancy), compared to rare species.

Knowledge of species' trends at local scales would be valuable for targeting conservation action towards areas with the strongest declines and for impact evaluation of local interventions. However, unstructured occurrence records are often analysed at course spatial grains e.g., 1 km (Outhwaite et al. 2020) or 5 km grids (Bowler et al. 2021). Coarse grains can be justified when the aim is to estimate average trends over a region or country. However, local time-series, where the same location has been revisited within and across years, provide opportunities for robust assessments of local change. Our survey suggests that many true time-series exist within the dragonfly unstructured data, since many recorders repeatedly visit the same sites. Indeed, the British Dragonfly Society promote an 'adopt a site' scheme that encourages participants to commit to repeated surveys at the same site within and across years. However, the relevant metadata are not available to distinguish these from other, more opportunistically collected, observations. While many recording platforms offer fields for location, sampling site names are not consistent or harmonized and the precision of geographic coordinates is variable. By contrast, structured schemes use unique site identifiers or codes. If consistent site identifiers could be included in the metadata for local time series, then recent developments in spatially explicit modelling could be leveraged to estimate change at fine scales and explore spatial variation in trends of occurrence and abundance (Fajgenblat et al. 2025).

A final opportunity offered by semi-structured insect data is modelling the distribution of breeding habitats using life stage metadata. This is relevant for all insects, because of the separate adult and juvenile stages, but dragonflies are a particularly good example of its importance. Like other freshwater insects, dragonflies rely on waterbodies, of types varying with species preferences, for breeding. Moreover, as highly mobile organisms in the adult stage, potentially moving over 1km (Minot et al. 2021), the distributions of adults will be much broader than the distribution of larvae. Life stage data is already available on many platforms, although most observations are of adults. Nonetheless, life stage metadata could be included in multi-state occupancy models that extend traditional occupied/not-occupied analyses based on adult observations to analysis that separates present and present and breeding based on observations of larvae or exuviae (Nichols et al. 2007). Such analysis could help identify likely breeding sites, and the factors shaping breeding site selection, to guide conservation planning on where to conserve and restore habitat.

Challenges with applying semi-structured monitoring to insects

Insects are a diverse group that require a diverse set of methods to monitor them. This creates complexity in designing a single platform to collect relevant metadata on sampling protocols for multiple insect taxon groups. Montgomery et al. (2021) proposed a set of standards for some of the most common insect sampling methods (Malaise traps, light trapping, pan trapping, beating sheet, acoustic monitoring and active visual surveys), highlighting recommended metadata for each. Their proposed metadata cover site description, temporal scope of sampling, weather condition experienced during sampling, as well as more specific protocol information that vary with the method (e.g., trap type and position). Because the necessary metadata vary with the sampling approach, different semi-structured recording forms may need to be developed for different approaches, but metadata collection should be aligned across forms wherever possible.

Beyond documenting the basic sampling methods used, insect sampling involving citizen scientists needs to consider additional metadata that reflects differences among recorders. For instance, citizen scientists vary in the scope of insect species that they can identify and are interested in reporting, which has implications for how list completeness is defined. For birds – as a discrete group with dedicated reporting apps – it is typically straight-forward for a recorder to report whether a reported species list was complete or not. Within multi-taxon platforms often used for insects, it becomes much more complicated since the target community also needs to be defined. As we found in our survey, many dragonfly recorders also report observations of other species at the same time as those of dragonflies, but the target community is not necessarily planned, and most insect sampling methods simultaneously capture insect species from diverse groups. Moreover, in platforms that focus on the reporting of images, many species that were observed might not be on the reported list (Ball and Morris 2021). Collectively, this means that the target group of list completeness for insects needs to be thoughtfully defined – either according to different taxonomic ranks (e.g., order or family) or allowing more flexible user-defined groups that reflect the varying expertise and interests of recorders when surveying.

Abundance data is also challenging to report for insects: individuals of different species can aggregate in large numbers and double counting hard to avoid. Within UK damselflies, blue damselflies are visually similar and can aggregate in too great a number to check individually. Reflecting these challenges, we found that the format of abundance data reporting varies across platforms, but is often collected on a categorical scale, based around abundance intervals, rather than exact counts. Any attempts to standardize the vocabulary of abundance data will need to navigate a trade-off between the reporting of exact counts or fine abundance intervals (best for precise modelling) and the reporting of abundance data in coarser intervals (more feasible for recorders). Moreover, improvements in the reporting of abundance data will need to be joined by related improvements in the reporting of survey effort, since the former is highly dependent on the latter. For species co-occurring in large aggregations, guidance could be given on counting the numbers of individuals and then allocating to species in proportion with those that could be identified (Pearce-Higgins and Chandler 2020).

Further types of metadata are also relevant for other insect groups, especially those related to species interactions, such as pollination or parasitism. The most popular UK platform for insects, iRecord, has dedicated reporting forms for some taxa; for instance, sawfly recorders can report the plant on which the larva was found. In international apps such as iNaturalist, it is also possible to add information on observed species interactions or such information can be retrieved from the images as secondary data. These opportunities have yet to be fully exploited but hold great promise for understanding the dynamics of insect populations and communities (Callaghan et al. 2021, Pernat et al. 2024).

Potential for structured schemes for insect monitoring?

Harmonized monitoring approaches within structured schemes, i.e. those employing a single sampling protocol with repeated visits to set sites, underpin some of the most successful examples of translating citizen science into policy-relevant biodiversity indicators, e.g. the farmland bird and grassland butterfly indices are used to report on impact of agriculture on biodiversity across the EU (del Pozo et al. 2023). However, apart from butterflies, structured citizen science monitoring is rarely used for insects. Structured, repeatable survey methods are available for dragonflies (Pearce-Higgins and Chandler 2020), but previous attempts to establish a fully structured monitoring scheme for dragonflies in the UK, France and Japan were only partly successful due to limited of uptake (although schemes have emerged in The Netherlands and Singapore). Here, we found that respondents were split in their willingness to adopt a single standardized protocol for dragonfly monitoring. Nonetheless, structured schemes can still be successful even with a small number of volunteers, providing sampling locations are representative and sampling methods detect enough individuals to derive robust estimates of change (Buckland and Johnston 2017).

Structured schemes themselves vary in their degree of structure (Schmeller et al. 2012) . One option for a semi-structured scheme for insects is a standardised protocol that specifies how data should be collected at sampling sites and times, but with freedom on when and where sampling takes place (Broughton and Pocock 2022, Hisano 2025). This would continue to provide flexibility for volunteers but reduces some of the sampling variability affecting the data. As a model for this form of monitoring, 15-min counts have been recently promoted in European butterfly monitoring, offering more structure (controlled effort) than opportunistic monitoring but less structure (no obligation for repeat surveys) than the standard Pollard walks deployed by the national structured schemes (Kral et al. 2018). Similarly, Flower Insect Timed counts are a component of the UK Pollinator Monitor Scheme and used in other countries (Roy et al. 2016); https://fitcount.ceh.ac.uk/). Early signs indicate that these semi-structured monitoring protocols are proving popular, but similar initiatives have not yet been attempted for other insect groups, and any differences in data quality from these protocols and fully standardized/structured schemes are unclear (Barkmann et al. 2023).

Moving forwards

Different types of data collection practices are needed to meet the multiple needs and objectives of monitoring (Wright et al. 2022). Most structured schemes are designed to produce estimates of mean abundance change through time and hence seek to sample a representative set of sites, with repeat sampling, even if that number of sites might be relatively low. Other monitoring schemes aim to map the distribution of a species at a regional or national scale, seeking to maximise the number of sampling locations to cover the full range of species, without any emphasis on repeat sampling. Both these objectives are valuable and are needed for different questions within scientific research and conservation. This means that, while creating opportunities to add structure to insect recording via improved metadata is important, it will be also important to remain open to multiple sampling approaches, including opportunistic and semi-structured recording.

Studies on citizen science agree that one of the motivations to participate in biodiversity monitoring is contributing to science and conservation, but enjoyment, increasing skills and knowledge, and feeling connected with nature are also important (Ganzevoort et al. 2017, Jansen et al. 2024). These different motivations may explain variation in willingness to commit to more structured monitoring for insects. In seeking opportunities to add structure to insect monitoring, co-design of survey protocols and providing guidance will be essential to align with volunteers' motivations and ensure the buy-in of the recorder community. However, our findings reveal that many recorders already collect insect species observations in structured ways, even if this is structure is not apparent in data aggregator databases. We believe that there are many quick wins that could be achieved by better metadata reporting, unlocking the full value of citizen science efforts and improving our understanding of the trajectories of insect populations and distributions.

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Supplementary Information

Additional figures and tables for 'The hidden structure of unstructured citizen science insect monitoring'.

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Contents

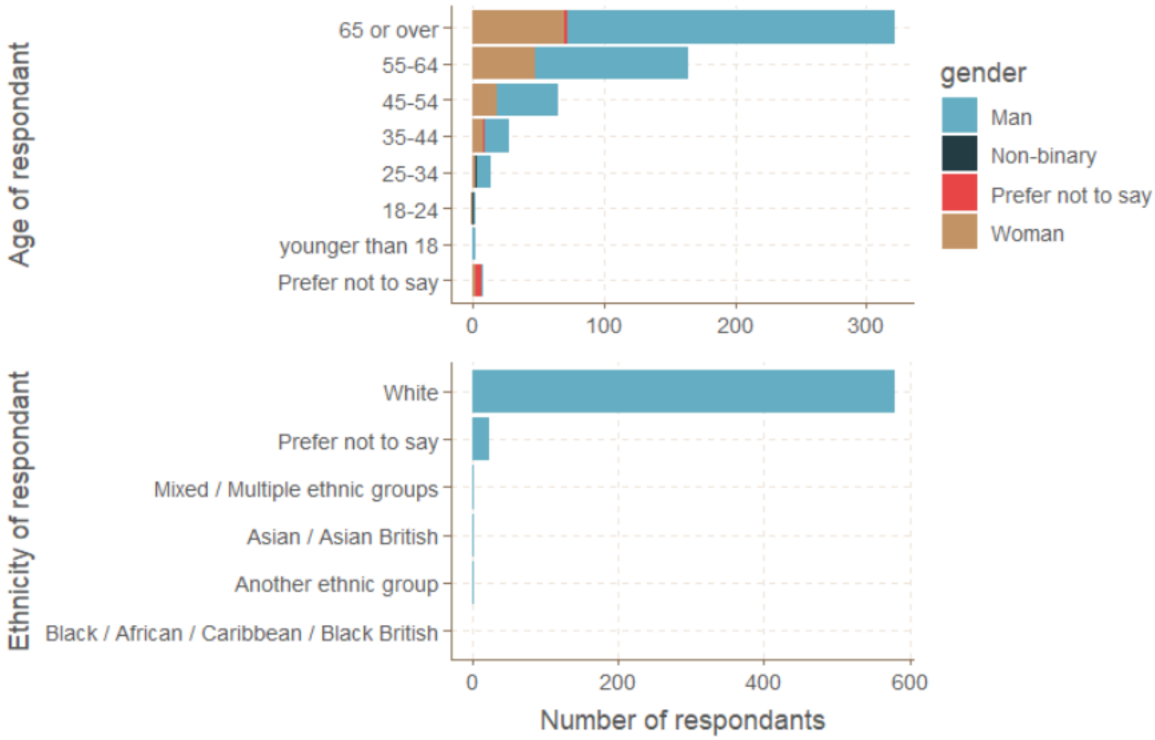

Fig. S1 Demographic profile of the respondents.

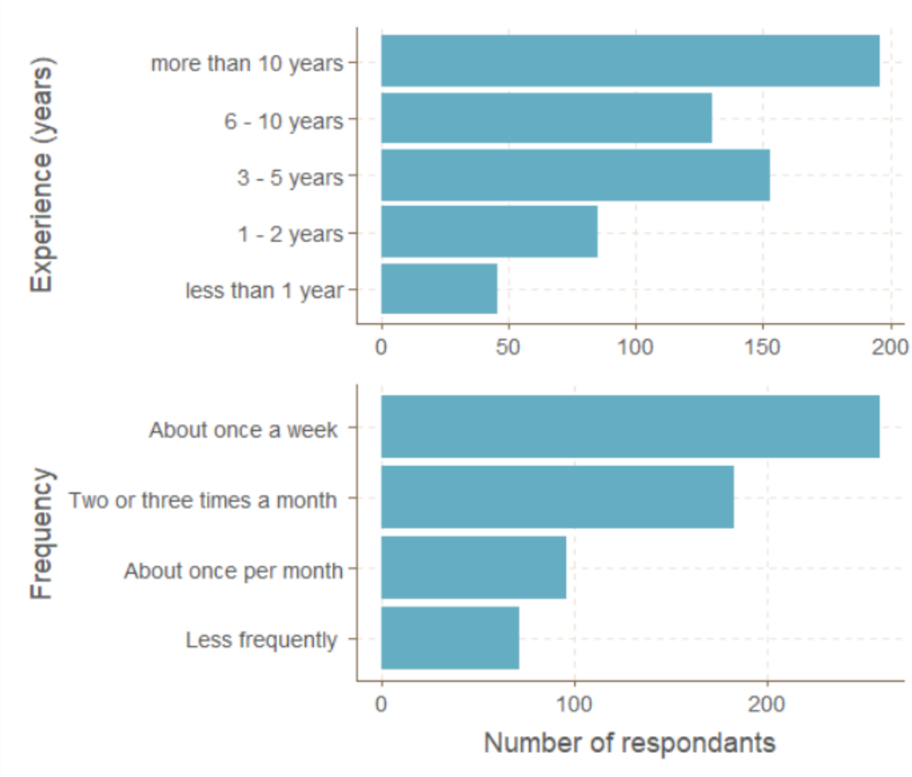

Fig. S2 Number of respondents who confirmed recording for different frequencies during 2024, and the total number of years that they have been involved in dragonfly monitoring.

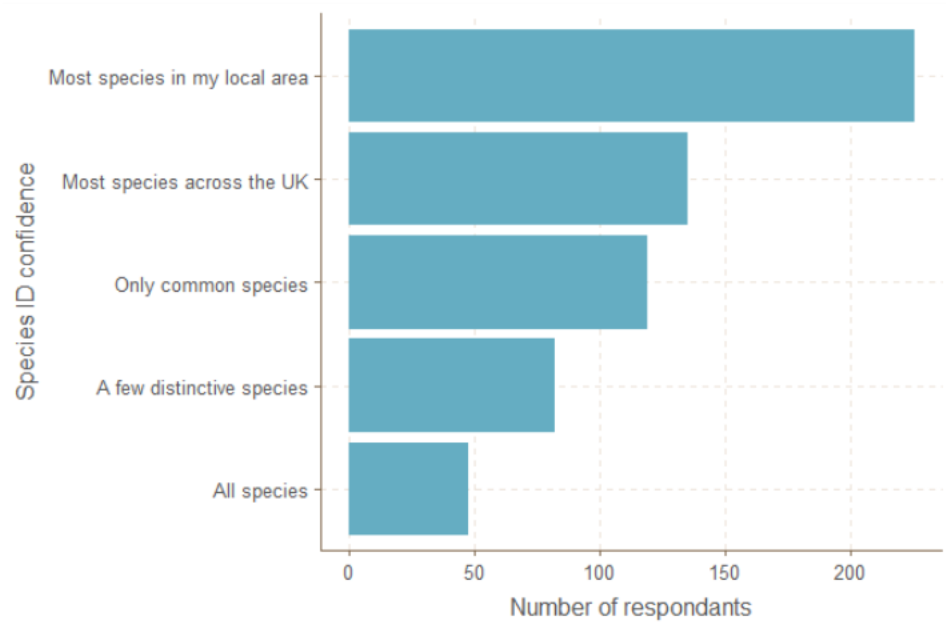

Fig. S3 Number of respondents confirming their species ID confidence at different levels

Table S1 Common species ID problems mentioned by respondents

Problem	Specific species
blues	Scarce Blue-tailed and Scarce Emerald Damselflies; Azure and Common Blues; Variable and Azure Blues
hawkers	Common and Southern hawker; Mosaic hawkers
emeralds	Willow Emerald and other Emeralds; Common and Scarce Emerald
demoiselles	Female banded and beautiful demoiselles
new arrival	Emeralds
darters	Common and Ruddy Darter
red-eyed	Red-eyed and Small Red-eyed

Table S2 Examples for each the reason ‘themes’ given for choosing a specific recording platform.

Theme	Components as described
Used for multiple taxa	Suitable for other taxa Already being used to report other taxa
Easy	Easy Flexible Convenient Quick
Recommended/Trustworthiness	Used or suggested by others, including the BDS Widely used Reliable/Stable
Useful tools	Tools for confirm species ID Ease of location documentation Download/upload options including photos Tailored forms/projects Submit full lists Ability to see records of others Use in field/finish at home
Verified/Feedback	Verification of observations Feedback on errors
Data are shared/used	Shared with: Verifiers Other organisations /platforms Data analysts Used to build knowledge and have impact
Central place for own records	Simplify reporting of observations Single location to store, view and analyse own photos and data
Familiar	Familiar Tradition
Other	For use by local organisations Support an organisation No sign in No photo needed

State and development of dragonfly monitoring

Project Background
Volunteers make enormous contributions to the monitoring of species, especially for invertebrate groups such as dragonflies. These monitoring data have revealed important insights into how dragonfly distributions are changing and the specific needs for conservation and environmental management. Volunteer recording is also diverse – with a range of different websites, apps and platform enabling people to collect and share data. In this project, we wish to learn about the preferences of volunteer recorders for different recording options, and their ideas and interest in extending dragonfly recording further. This research is part of the 'Terrestrial Surveillance Development and Analysis' (TSDA) project that seeks to develop and enhance volunteer-recording of biodiversity in the UK. The project webpage for TSDA is here.

Who are we?
This project is led by the UK Centre for Ecology & Hydrology, in close collaboration with the Joint Nature Conservation Committee and the British Trust for Ornithology.

Who should complete this questionnaire?
Anyone collecting and reporting observations of dragonflies and/or damselflies who wishes to help us improve how we use volunteer-collected data. We welcome both beginners and experts, as well as specialists and generalists. You could be collecting and/or sharing data in a variety of ways - whether through an app or website (e.g., iRecord or BirdTrack), a personal spreadsheet or database, or any other way.

About this questionnaire
We will ask you a series of questions about your data collection and reporting preferences. At the end of the questionnaire, you will be given an opportunity to make any additional comments about dragonfly recording that you think are relevant. There are no right or wrong answers – we wish to simply hear from your own experiences. Note that when we mention dragonflies, we always mean both dragonflies and damselflies.

The questionnaire should take about 15 minutes to complete, however, you will have the option to save your response and continue the questionnaire later should you wish. If you have any questions, comments, or concerns, please email Diana Bowler (diabow@ceh.ac.uk).

Thank you for your cooperation!
Diana Bowler, Michael Pocock & Robin Hutchinson, UK Centre for Ecology & Hydrology

Privacy notice and consent

Your participation in this survey is completely voluntary, and you can withdraw from participating at any time or skip any questions you do not wish to answer. No statement will be directly attributed to a specific individual in the results of our project. The data generated from this survey will be kept until the end of the project and may be used in a scientific publication. Any use of your personal data will adhere to the principles expressed in the UKCEH privacy notice available here. You can download a participation information sheet here and a privacy statement here. *

- [ ] I understand that my consent to participate in this research project is voluntary and that I am free to withdraw this consent at any time without giving any reason
- [ ] I agree to participate

In this section, we wish to learn about your experience in dragonfly recording.

How long have you been collecting data on dragonflies? I have been active .... *

- ◯ less than 1 year
- ◯ 1 - 2 years
- ◯ 3 - 5 years
- ◯ 6 - 10 years
- ◯ more than 10 years

What role do you play in dragonfly recording? Tick all that apply. *

- ☐ I note down/record species observations
- ☐ I submit/share these observations to an organization or recording platform
- ☐ I verify the observations of others
- ☐ I organise a recording group

Please answer the remaining questions if you selected any of these boxes. Please also answer them with respect to your own personal observations of dragonflies.

If you were active this year, how often did you collect data on dragonflies during the flight season? *

- ◯ About once a week
- ◯ Two or three times a month
- ◯ About once per month
- ◯ Less frequently

How confident are you in your dragonfly species identification skills?
I am confident in identifying ... *

- ◯ All species
- ◯ Most species across the UK
- ◯ Most species in my local area
- ◯ Only common species

○ A few distinctive species

(Optional) Please make any general comments about your experience or expertise e.g., are there any species that you have trouble separating?

0/32,000 characters

How do you share your observations?

Thinking over this year, which platform(s) did you use to submit your dragonfly observations? *

iRecord

- ◯ never
- ◯ rarely
- ◯ sometimes
- ◯ often
- ◯ always

iNaturalist

- ◯ never
- ◯ rarely
- ◯ sometimes
- ◯ often
- ◯ always

Butterfly Conservation / Butterfly Count

- ◯ never
- ◯ rarely
- ◯ sometimes
- ◯ often
- ◯ always

NatureSpot

- ◯ never
- ◯ rarely
- ◯ sometimes
- ◯ often
- ◯ always

BTO Garden Watch

- ◯ never
- ◯ rarely
- ◯ sometimes
- ◯ often
- ◯ always

BirdTrack

- never
- rarely
- sometimes
- often
- always

Observation.org

- never
- rarely
- sometimes
- often
- always

Direct to County Recorder

- never
- rarely
- sometimes
- often
- always

Local Records Centre

- never
- rarely
- sometimes
- often
- always

Other

- never
- rarely
- sometimes
- often
- always

If you selected 'Other', please explain here:

0/32,000 characters

(Optional) Please briefly explain why you use your most preferred platform?

0/32,000 characters

In this section, we are asking you about how you collected dragonfly observations this year. Please rate the frequency with which each statement applies to your observations.

My submitted records were based on... *

observations of adults

- Never
- Rarely
- Sometimes
- Often
- Always

observations of exuviae

- Never
- Rarely
- Sometimes
- Often
- Always

observations of larvae/nymphs

- Never
- Rarely
- Sometimes
- Often
- Always

My observations were made... *

opportunistically, while I am going about other activities e.g., going for a walk

- Never
- Rarely
- Sometimes
- Often
- Always

during a planned survey, when I visit a place with the specific aim to record species

- Never
- Rarely

- Sometimes
- Often
- Always

while at home, in my garden

- Never
- Rarely
- Sometimes
- Often
- Always

My observations comprised.... *

all the dragonfly species that I saw and could identify (i.e., a complete checklist)

- Never
- Rarely
- Sometimes
- Often
- Always

only sightings that I thought were interesting e.g. first of the year, or scarce species

- Never
- Rarely
- Sometimes
- Often
- Always

other taxa (e.g., birds and butterflies) at the same time as dragonflies

- Never
- Rarely
- Sometimes
- Often
- Always

In terms of location, I like to record at... *

the same site or sites

- Never
- Rarely

- Sometimes
- Often
- Always

new sites

- Never
- Rarely
- Sometimes
- Often
- Always

We are interested in scoping how we could add more structure or design to dragonfly monitoring in the UK. Large-scale structured monitoring focused on other taxa, such as birds, usually involves a standard protocol that is repeated over multiple visits to the same sites. Some data for dragonflies are already collected in structured ways, but monitoring is diverse. How do you feel about the following possible design aspects for dragonfly monitoring?

Please use the comments section below to expand on your answers. *

Following a standard protocol that specifies a sampling method (e.g., point count or line transect)

- ◯ I already do this
- ◯ I would be willing to do this several times a year
- ◯ I might consider this
- ◯ This would not work for me

Visiting the same site several times during the same year (e.g., as part of the British Dragonfly Society 'Adopt a Site' project)

- ◯ I already do this
- ◯ I would be willing to do this several times a year
- ◯ I might consider this
- ◯ This would not work for me

Reporting a complete checklist (i.e. reporting all dragonfly species that you see)

- ◯ I already do this
- ◯ I would be willing to do this several times a year
- ◯ I might consider this
- ◯ This would not work for me

Pre-assigned site selection (e.g., being assigned a site to visit, usually near to where you live)

- ◯ I already do this
- ◯ I would be willing to do this several times a year
- ◯ I might consider this
- ◯ This would not work for me

Recording species abundance (i.e., number of individuals seen of each species)

- ◯ I already do this
- ◯ I would be willing to do this several times a year
- ◯ I might consider this
- ◯ This would not work for me

Recording ‘zeros’ (i.e., when you do not see individuals of any or all species)

- I already do this
- I would be willing to do this several times a year
- I might consider this
- This would not work for me

Recording additional information (e.g., habitat or waterbody information)

- I already do this
- I would be willing to do this several times a year
- I might consider this
- This would not work for me

Recording sampling effort or distance information (e.g., minutes spent looking, distance covered during search)

- I already do this
- I would be willing to do this several times a year
- I might consider this
- This would not work for me

Please add any comments to explain why you selected your responses above.

0/32,000 characters

Any other comments

(Optional) In the space below, you are free to make any other final comments you'd like to make about dragonfly monitoring, whether about current practices or future possible practices.

0/32,000 characters

A bit more about you (optional)

In this section, we ask you for some information about yourself. This is simply to ensure we are reaching and collecting opinions from a broad demographic.

What is your age group?

- ◯ younger than 18
- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ 65 or over
- ◯ Prefer not to say

What is your gender

- ◯ Woman
- ◯ Man
- ◯ Non-binary
- ◯ My gender is not listed
- ◯ Prefer not to say

What is your ethnicity?

- ◯ White
- ◯ Mixed / Multiple ethnic groups
- ◯ Asian / Asian British
- ◯ Black / African / Caribbean / Black British
- ◯ Another ethnic group
- ◯ Prefer not to say

Your recording activities beyond dragon/damselflies (optional)

In this section, we ask you a set of standard questions that we include in all our questionnaires about biological recording. You might feel some of the questions overlap with earlier ones, but please answer them with regards to your recording of all and any species groups, not just dragonflies and damselflies.

How often do you currently participate in biological recording? If you record for more than one scheme, please total your participation across all schemes. If you record for a taxa that is seasonal (e.g. butterflies, fungi), please only consider frequency during the typical recording season.

- ○ Usually weekly, or more often
- ○ Usually between weekly and monthly
- ○ Usually between monthly and quarterly
- ○ Usually between quarterly and annually
- ○ Usually less frequently than annually
- ○ Never

How long have you been a regular participant (annually or more often) in biological recording? If you participate in more than one scheme, please answer in relation to the scheme that you have had the longest continuous involvement with.

- ○ Less than 1 year
- ○ 1-2 years
- ○ 3-5 years
- ○ 6-10 years
- ○ More than 10 years
- ○ I don't regularly participate in biological recording

How confident are you in your identification skills for the type of organism (e.g., birds, plants or butterflies) that you record for? If you record for more than one type of organism, then please answer only for the type that you have highest confidence in.

- ○ Low confidence – I consider myself to be a beginner recorder
- ○ Medium confidence – I consider myself to be an intermediate level recorder
- ○ High confidence - I could be described as an expert recorder
- ○ I don’t currently participate in biological recording