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RESEARCH ARTICLE

Slugs Count: Assessing citizen scientist engagement and development, and the accuracy of their identifications

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Abstract

1. How accurately can citizen science participants identify species, and can the information they provide be used to calculate accurate estimates of species richness, abundance and diversity measures? In this paper, we address these questions using data from a citizen science project assessing slug species diversity in gardens.
2. Sixty participants were selected from over 2700 applicants across Britain to sample their gardens regularly for slugs following a standardised method. All slugs collected during the 30-min search were posted to the lead investigator for verification throughout the 12-month project. The resulting data were analysed to explore how accurate participants were in identifying slugs and whether this improved over the study period. Prior experience in slug identification was evaluated as a predictor of accuracy.
3. Participants overestimated slug abundance and species richness, which led to overestimates in species diversity indices, illustrating the importance of verification in citizen science projects involving identification.
4. Accuracy of slug identifications increased significantly over time in quantitative analysis of ecological data. However, self-defined prior experience of identifying slugs before participation was not a good predictor of participant accuracy.
5. Participants reported perceived improvement in slug identification skills to an evaluation survey after the project. However, confidence in identifying and explaining identification of slugs was lower than confidence in understanding and explaining other new science topics.
6. This citizen science approach, including expert verification of physical specimens, illustrates how this method can be used successfully to provide accurate data on species' abundance and richness, alongside improving identification skills among the public for an understudied taxon. Continued engagement and feedback for participants is key in retaining citizen science participation in a project of this type, particularly if the taxon is challenging to identify correctly to species.

KEYWORDS
citizen science, data quality, gardens, slugs, species diversity

1 | INTRODUCTION

How accurately can citizen science participants identify species, and can the information they provide be used to calculate accurate estimates of species richness, abundance and diversity measures? In this paper, we address these questions using data from a citizen science project assessing slug species diversity in gardens. Citizen science can achieve much greater spatial coverage over a shorter time than studies conducted solely by professional scientists (Hochachka et al., 2012; Lye et al., 2012; Pocock & Evans, 2014; Weiser et al., 2019) and contribute greatly to our understanding of changes in biodiversity, including the spread of non-native species (Delaney et al., 2008; Roy et al., 2015; Turóci et al., 2020; Vendetti et al., 2018, 2019). Short-term citizen science projects can generate large amounts of high-quality data; the Big Wasp Survey generated spatial data equivalent to four decades of expert recording within 1 week (Sumner et al., 2019). Previous attempts have been made to quantify the diversity of slugs and snails found in British gardens using citizen science approaches, but with limited success (Dussart, 2019; North & Bailey, 1988). The present study was planned with a detailed sampling protocol and assessment of participant skills before and after the project as described below.

Data accuracy and quality are essential to the success of citizen science projects, being highly dependent on project design and application, volunteer training and testing, replication across volunteers and expert validation of data (Kosmala et al., 2016). However, retention of volunteers throughout the duration of citizen science projects is a common problem and can be more difficult for projects with intensive methods such as systematic approaches, including repeat sampling of sites, compared to unstructured approaches (Weiser et al., 2019). Consistent and repeatable sampling effort and protocols can be important for some citizen science projects, which might otherwise be subject to sampling bias resulting in the over reporting of rare species and under reporting of common species (Dickinson et al., 2010; Hochachka et al., 2012; Roy et al., 2016). Therefore, this study, Slugs Count, chose a structured repeat sampling design, asking citizen scientists to collect multiple samples from their garden regularly throughout the year using a standardised method. As the main aim of the project was to assess species diversity, accurate identification of slugs was essential.

Verification of citizen science data has become of increasing concern to the research community, with verification recognised as a critical process in ecological citizen science projects (Baker et al., 2021; Pocock & Evans, 2014; Roy et al., 2016). Accurate photo identification of species groups in citizen science projects has been used (Lye et al., 2012; Sharma et al., 2019; Worthington et al., 2012), including citizen science surveys for individual slug species (Dörler et al., 2018; Morii & Nakano, 2017). However, as a fauna, slugs can be highly variable and challenging to identify accurately to species solely from photographs, with several cryptic species requiring collected specimens to confirm identifications (Rowson, Turner, et al., 2014; Schilthuizen et al., 2022; Vendetti et al., 2019). The highly reflective nature of slug body slime also makes it challenging and time consuming to create photos of sufficient quality for accurate identification, particularly if samples contain more than a few individuals. Therefore, to accurately record the complete garden fauna of slugs, physical specimens are required for verification. While verification of voucher specimens can result in increased cost, the cost of verified citizen science has been acknowledged as being up to two thirds less than the use of traditional science sampling techniques of sending professionals out to take multiple samples (Gardiner et al., 2012). Collecting standardised samples of slug specimens for long term preservation also creates a valuable resource to answer future research questions on subjects from taxonomic identity to the abundance of parasitic organisms. Increasing knowledge and understanding of the ecology of slugs was an important aim of the project and therefore encouraging participants to identify the slugs sampled was considered valuable with expert verification included as a check.

Bias specific to citizen science projects includes variability among volunteers in prior experience and attitudes; but training is likely to increase data reliability, particularly if volunteers are following a standardised methodology (Kosmala et al., 2016; Roy et al., 2016). Weighting volunteer identifications by skill level is of increasing interest to the field of citizen science (Kosmala et al., 2016). However, there is limited evidence of evaluation of participant identification skills prior to commencing projects and how this influences data quality output. This study assessed participants' prior experience of slug identification to investigate whether this influenced accuracy.

The importance of providing training to participants in citizen science projects has been widely recognised as important for data quality and engagement (Dickinson et al., 2010; Kosmala et al., 2016). Identification skills will improve with regular participation, particularly within the first year of a project (Dickinson et al., 2010), though this may vary between individuals (Foster-Smith & Evans, 2003). Providing ongoing personalised support from professional scientists can help reinforce training and improve data accuracy (Dickinson et al., 2010) and therefore was considered in the design of this citizen science project.

Retaining participants in citizen science projects is a priority, to maximise the amount of data collected, resulting in greater statistical power to detect changes in abundance and population trends (Beirne & Lambin, 2013). However, recruiting and retaining participation in a citizen science project on slugs has the potential to be challenging, not only because of the commitment required but also because of the perception and values of participants regarding the target taxonomic group. Contact with invertebrates through gardening activities has been shown to reduce levels of irrational fear and disgust of organisms. However, in both gardening communities and the general public, slugs are regarded with high levels of disgust and fear, and classed more frequently as pests in comparison to other common garden invertebrates (Davey, 1994; Driscoll, Janis Wiley, 1995; Vanderstock et al., 2022). Therefore, retaining participants for repeated sampling of a garden for an unvalued taxon could be challenging. Repeat sampling ecological citizen science projects have reported approximately 40%–50% of participants retained after 6 months (Greving et al., 2022; Shinbrot et al., 2023).

The main purpose of this project was to assess species diversity in gardens, but the secondary aims, reported in this paper, were to investigate how accurately citizen science participants can identify slugs to species, and whether the information they provide can be used to calculate accurate estimates of species richness, abundance and diversity measures. In addition, we investigated whether prior experience of slug identification influenced accuracy, and if those with little or no prior identification experience improved over time to become as accurate as those individuals with intermediate to expert levels of experience. Self-perceived development in identification skills was also of interest, to establish whether participants felt that their slug identification skills increased due to participation in the project, and to identify whether this perceived improvement matched the measured change from the ecological data submitted.

2 | MATERIALS AND METHODS

2.1 | Participant selection

Applications for participating in the Slugs Count project opened in January 2020 and the project was advertised across a range of media outlets, including national radio stations and the BBC news website (BBC, 2020), as well as social media platforms. Potential citizen scientists, hereafter referred to as participants, were directed to the Slugs Count project webpage and asked to fill in a screening survey via SurveyMonkey. Applicants were required to answer a set of questions aligning with the project's requirements, to allow screening of applicants for their suitability for involvement in the project (see Supplementary Material). Due to the impact of the COVID-19 pandemic, participant selection was delayed until August 2020. Participant selection first consisted of essential applicant criteria (Table 1), then favoured applicants with prior slug identification experience and applied stratified sampling of participants based on location.

During the recruitment process, participants were asked to self-evaluate their experience in identifying slugs (Table 2). Once essential criteria had been applied, applicants were filtered by experience level, so that participants with Intermediate to Expert level experience were selected to participate first. This was due to a very small number of applicants having prior slug identification experience (Table 3), and so that these could be well represented in data analysis. This resulted in a selection bias towards those applicants who had higher levels of experience of slug identification, with 8% of all applicants having experience levels of intermediate, advanced or expert level, but 20% of selected applicants having these skill levels.

British National Grid projections were estimated for the location provided by applicants, and were imported into QGIS. A layer containing single letter British National Grid squares was overlaid, and at least three applicants were selected per grid square to create a shortlist of 100 participants from the 2791 applications received.

TABLE 1 Essential participant selection criteria used to filter Slugs Count applications.

Criteria
Mainland Britain location
Garden 100 m^2 or larger
Stated garden a “mix of garden features”
Garden not likely to be significantly altered within the study timeline
Participants willing to touch and package slugs to post to researcher
Able to drop off parcels within a 24 h period at nearest post office or parcel box

TABLE 2 Slug identification experience categories and definitions used for the question: “What experience do you have identifying slugs to species?”.

Category	Definition
None	Not tried before
Beginner	Some experience
Intermediate	Moderate experience
Advanced	A lot of experience
Expert	Vast experience

Only participants in mainland Britain were considered to minimise the effect of isolation within the slug fauna from other islands (Simberloff, 1974).

From the shortlist of 100 people, the first 60 to reply after being notified that they had been selected as potential participants were included in the project. Participants were provided with the opportunity to attend training sessions on survey methodology and slug identification which took place over Zoom (see Supplementary Material). Presentations included questions and polls to assess understanding and learning. These sessions were recorded so participants who could not attend the live sessions could view them later.

2.2 | Data collection of slug species identifications

Data collection for the Slugs Count project took place between October 2020 and October 2021. All participants were sent a kit containing materials they needed, including plastic containers, capillary matting, postage envelopes, head torch and a copy of the identification key by Rowson, Anderson, et al. (2014) Slugs of Britain and Ireland. To manage data flow and ensure equal year-round coverage, the 60 participants were divided into four groups, with each group surveying once every 4 weeks. These four groups were further divided into three sub-groups, and allocated either Sunday, Monday or Tuesday to carry out their surveys. All participants were asked to survey 1 h after sunset for a 30-min time period in a methodology adapted from Barnes and Weil (1944, 1945). They were asked to choose a survey route and document it, then follow this same route each time throughout their gardens, collecting any active slugs they found. They then had up to 48 h to identify the slugs they found,

TABLE 3 Numbers and percentages of applicants and participants in the project with self-reported slug identification experience.

Experience level	Number of applicants	% of applicants	Number of participants selected	% of participants selected
None (not tried before)	1788	60.7	26	43.4
Beginner (some experience)	926	31.5	22	36.7
Intermediate (moderate experience)	208	7.1	5	8.3
Advanced (a lot of experience)	17	0.6	5	8.3
Expert (vast experience)	3	0.1	2	3.3

before posting the live material to I. Cavadino, hereafter referred to as the investigator, at the Royal Horticultural Society (RHS) via a Royal Mail business response service.

Slugs are soft-bodied, so prone to rapid decay if not preserved correctly. The preservation of slugs requires storage in 70%–80% ethanol, but this concentration of ethanol is classed as a flammable substance and prohibited from being sent via the majority of postage systems in Britain (Royal Mail, 2023). However, the transport of live invertebrates is permitted by Royal Mail, as long as various conditions of carriage are fulfilled (Royal Mail, 2023). Therefore the novel approach of having citizen science participants send live material for verification was selected for this study. This also had the benefit of ensuring both citizen scientists and the investigator were using the same identification characteristics for identification, as slug identification often relies on external characters that can fade or change on preservation in ethanol.

Specialist materials, packaging and guidance were supplied to participants to ensure slug survival in the post and to comply with Royal Mail requirements for posting live invertebrates. Participants were asked to place no more than 20 slugs per 1000 mL plastic container to discourage aggressive interactions from overcrowding, with one piece of damp capillary matting and a supply of carrot per box. Once received, parcels were stored in the fridge until slug identifications were checked by the investigator, and slugs were relaxed in carbonated spring water and then transferred to 70% ethanol for long term storage.

2.3 | Analysis of participants in accuracy of slug abundance, richness and diversity measurements

Data were analysed using R (R Core Team, 2022). To analyse accuracy in identification, any surveys where no slugs were observed and collected by the participant were removed from the dataset. Two participants found no slugs in any of their surveys, so were excluded from the analysis for identification accuracy. Data from the first survey was also discarded from analysis, due to changes in slug identification methodology. Prior to the first survey, experienced participants were allowed to send in single representatives of each species they were confident of identification, along with any material they were unsure of. However, during the first set of survey verification this approach was recognised as an unfair representation of accuracy, so all participants were advised to send all slugs collected from their second survey onwards.

Accuracy in abundance and species richness measurements was assessed by comparing participant's data to the data recorded in the lab by the investigator. Slugs that could not be identified by the participant or investigator were excluded in species richness and species diversity measures. The Shannon Diversity Index was calculated for each surveyor, once using participant identifications and again using the investigators identifications. Pairwise Wilcoxon tests and one sample dominance tests were used to explore differences in abundance, species richness and diversity estimates between participants and the investigator.

2.4 | Assessing participants self-described development

A survey was sent to everyone who had participated in the Slugs Count project (see Supplementary Materials) using Google forms. This evaluation survey requested demographic data to evaluate the reach of the project, and a range of questions on participant skills development and enjoyment throughout the project. A sub-set of eight questions were adapted from the Skills of Science Enquiry, and Self-Efficacy for Learning and Doing Citizen Science Toolkits created by Cornell Lab of Ornithology (Phillips et al., 2017a, 2017b), asking participants to reflect on experience levels prior to the experiment and after the experiment. Responses were on a five-point scale from Strongly Disagree to Strongly Agree. The questions on experience levels before and after the project were treated as ordinal data. Two-sample paired sign tests from the Nonpar package (Lukke Sweet, 2022) were used in R (R Core Team, 2022) to calculate differences between responses for prior to and after participation in the project. Dominance statistics were calculated to measure effect size, looking at the proportion of observations greater than the default median value minus the proportion of observations less than the default median value (Mangiafico, 2016).

2.5 | Improvements in accuracy over time

Measurements of species richness may mask identification mistakes, as the same count of species for participant and investigator could occur despite changes in identifications upon verification of material. To account for changes in species identifications made by the investigator, misidentification scores were calculated:

$$\text{Misidentification Score} = \frac{\left(\frac{\sum |a-b|}{2}\right)}{c}$$

This equation represents the sum of the absolute differences between the abundance of each species as measured by the participant ***a*** and the abundance of each species as measured by the investigator ***b***, then divided by two (to prevent double counting slugs that were removed from one species tally and added to another). The resulting number was then divided by total species abundance recorded by the investigator ***c*** to calculate a proportional "misidentification score" per participant. Misidentification scores were bounded by zero and one, except in a small number of cases where slug identifications had been sent but no material was received by the investigator from the participant. Scores higher than one were excluded from further analysis.

Due to the low number of participants with prior slug identification experience, participants who self-evaluated having experience levels "Intermediate", "Advanced" and "Expert" were pooled into a category of "more experienced", while those with low level experience were retained in "none" and "beginner" categories for analysis of the effect of experience on accuracy.

To investigate whether participant accuracy improved over the duration of the project, a binomial mixed effect model was created using the lme4 package in R (Bates et al., 2015). Survey number was used as a proxy for time, and identification experience was used as a grouping factor. Individual surveyor was included as a fixed effect to account for different levels of accuracy between individuals.

2.6 | Participant retention and engagement

Throughout the project, communication was maintained with all participants via email, with survey reminders sent out 3–4 days prior to scheduled surveys. Participants were also provided with individual feedback, comparing their lists of slugs species and counts with those made by the investigator, via email between surveys. This also allowed more experienced participants to query any identifications they did not agree with. A short update session was made available to all participants in June 2021, with live webinars and recordings. Final sessions were held at the end of the project in February 2023. These sessions included presentations of project results, and interactive activities to gather more feedback from participants, volunteers and others involved in the project on their experiences.

2.7 | Ethical approval

Ethical approval for this project was sought and received from Newcastle University (Ref: 9517/2018), including for the capture, use and killing of live invertebrates, as well as the involvement of human participants and the capture of personal information via questionnaires. Further advice and approval was received from the Royal Horticultural Society on the use of questionnaires, handling and storage of personal data and compliance with General Data Protection Regulations. The requirement for further ethical approval was reviewed regularly throughout the project when any changes or further requests for personal data was made. Written informed consent was obtained from participants at several stages throughout the study, including during initial recruitment and with each questionnaire. The privacy policy and right to withdraw from the study was also referred to at multiple stages of the project, including within webinars and on the project webpage. Photos of identifiable people within the Supplementary Material accompanying this paper appear with the individuals consent.

3 | RESULTS

3.1 | Slug species

A total of 20,374 slugs were collected by participants and identified to species by the investigator, representing up to 34 species (Table 4).

3.2 | Accuracy; measuring slug abundance

In total, 22,790 slugs were collected by participants, with 22,125 of these successfully received by the project team (97%), arriving in a state suitable for identification. Participants recorded 2343 slugs as "unidentified" (10%). However, 62 slugs (0.28%) received were also unable to be identified to family, genus or species level by the investigator due to advanced states of decay. Ultimately, 20,373 slugs were successfully recorded by the investigator (Table 4) once all survey 1 data was excluded.

A difference was observed between the total abundance across all species of slug recorded by participants and that recorded from the slugs received by the investigator. Plotting the differences in abundance between these measurements using a Bland–Altman plot (Figure 1) indicated a mean difference of 3.70. Generally, a smaller number of slugs resulted in a higher level of precision by participants in measuring abundance. A paired samples Wilcoxon Test showed significant differences in overall abundance measures by participant and investigator, $Z=-2.83$, $p<0.05$. A one sample dominance test indicated that participants were most likely to record a higher abundance than the investigator, with 60% of individuals overestimating species abundance, resulting in a dominance proportion of 0.33 ($n=57$).

3.3 | Accuracy; measuring species richness

The mean species richness recorded by participants was 13.88 (SD = 5.27), while the mean species richness recorded by the

TABLE 4 Summary of slug species detected during Slugs Count across all sites ($n=60$) in descending order of total abundance and the number of sites occupied.

Species	Abundance	No. of sites occupied
Deroceras invadens	2821	52
Arion hortensis	2394	48
Arion subfuscus	2196	48
Ambigolimax spp	2136	48
Deroceras reticulatum	2124	51
Limacus maculatus	1967	48
Arion flagellus	1324	30
Arion rufus	1270	35
Arion owenii	1080	23
Arion distinctus	622	48
Arion ater agg.	464	30
Arion vulgaris	390	18
Arion hortensis or distinctus	369	18
Limax maximus	290	27
Tandonia budapestensis	214	28
Tandonia sowerbyi	144	10
Arion occultus	116	6
Arion ater seg.	104	17
Tandonia cf. *cristata*	81	6
Deroceras agreste	62	16
Unidentified slugs	50	17
Lehmannia marginata	49	12
Arion circumscriptus circumscriptus	20	9
Milax gagates	16	4
Arion fasciatus	11	5
Arion intermedius	8	5
Limacus flavus	8	3
Arionidae	6	5
Arion circumscriptus silvaticus	6	5
Arion cf. *fagophilus*	6	3
Boettgerilla pallens	6	6
Deroceras laeve	5	3
Deroceras sp	3	1
Arion (*Kobeltia*)	3	2
Arion sp "Davies"	3	3
Arion (*Carinarion*)	1	1
Arion cf. *iratii*	1	1
Limacidae	1	1
Phenacolimax major	1	1
Vitrina pellucida	1	1

investigator was 12.12 (SD = 3.43) (Figure 2). A paired samples Wilcoxon Test showed significant differences between the median species richness measures by participants and the investigator, $Z=-3.27$, $p<0.001$.

Plotting differences between species richness measures by participant and investigator (Figure 3) showed participants both under and overestimated species richness. However, the majority of points fell above zero, indicating that participants were most likely to overestimate species richness. This was supported by a one sample dominance test of differences observed in species richness, with a proportional dominance of 0.68 observations by participants overestimating species richness.

3.4 | Accuracy; estimating species diversity

Differences between the two Shannon Diversity measures calculated from data by participant and investigator were observed (Figure 4), with a wider estimate of species diversity observed in the data generated by participants. A pairwise Wilcoxon test showed that differences between these species diversity measures were significant, $W=-4.69$, $p<0.05$. A one-sample dominance test indicated that the participant data was most likely to overestimate species diversity by a proportion of 0.26.

3.5 | Participant's self-described development

Through the evaluation survey, participants scored themselves as increasing in scientific skills in submitting slug observations, understanding collection protocols, collecting standardised data, closely observing and recording slugs, and identifying slugs accurately. Running two-sample sign tests on these paired questions showed these self-perceived increases in skill to be statistically significant (Table 5). The negative value dominance statistics indicate that scores after participation in the project were larger than prior to participation in the project.

Participants were also asked to evaluate their experience level prior to and after participation in the project (Figure 5), using the same categories as previously used in the recruitment survey (Table 2). For analysis, each category was given a score of 1–5 (no experience—expert level experience). Participants reported a mean score of 1.38 (SD = 0.79) prior to participation, and a mean of 2.8 (SD = 0.46) after participation, an average increase of 1.42 skill levels. The majority of participants reported an increase in skill level, with only one participant reporting a decrease in skill; from expert to advanced level. One participant reported a large increase from no experience to advanced, but no participants reported the maximum increase in skill level from none to expert. A paired two sample sign test showed that reported increases in expertise were statistically significant, $n=57$, median difference −1 (95% confidence interval −2, −1), $p<0.0001$, with effect size (dominance) statistic of −0.91, indicating that 91% of respondents reported a significant increase in slug identification experience after participating in the project.

Questions adapted from the Cornell Lab self-efficacy for learning and doing citizen science evaluation toolkit (Phillips et al., 2017a) relating to general scientific learning resulted in a mean of 4.10

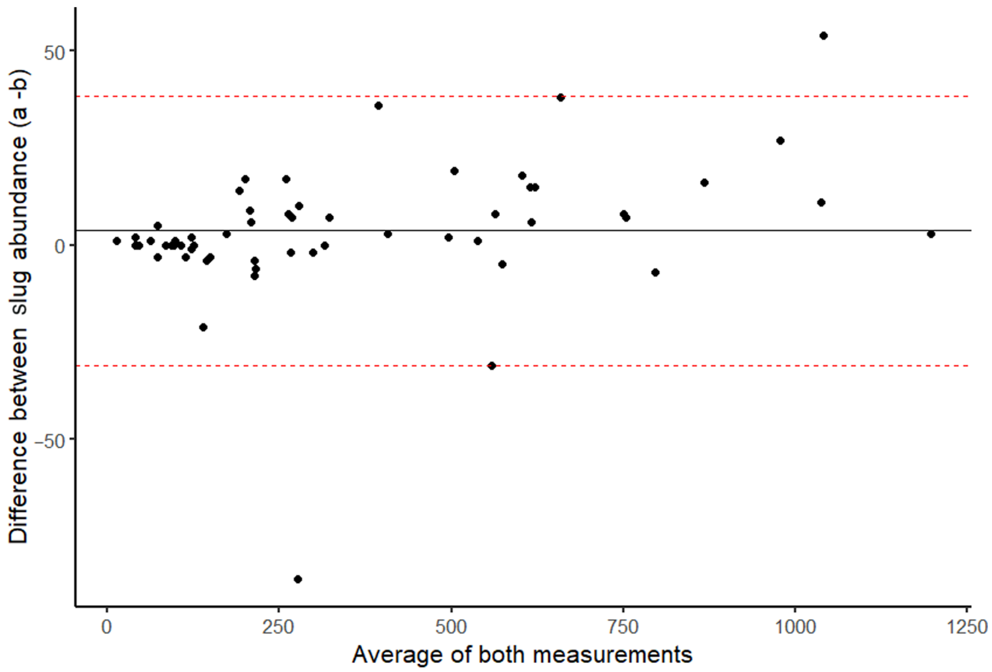

FIGURE 1 Bland–Altman plot of differences in total slug abundance measurements between (a) individual Slugs Count participants and (b) investigator's records (n = 57), with mean difference (black line) and 95% confidence limits (red dashed lines).

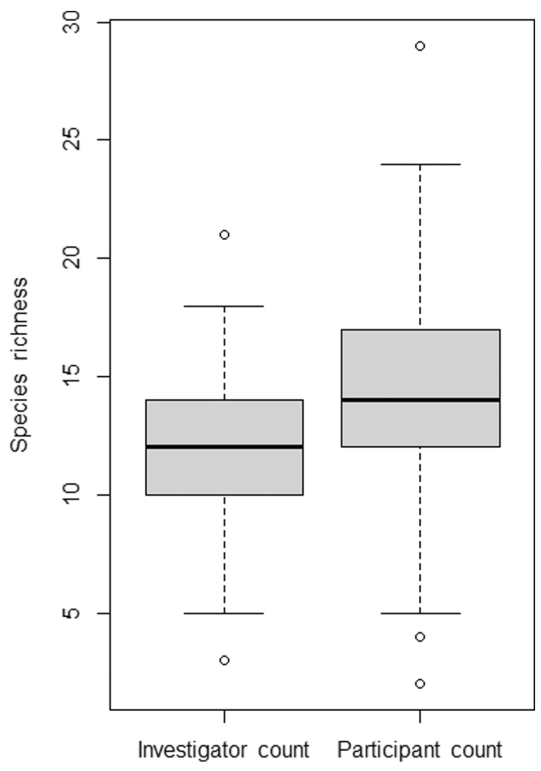

FIGURE 2 Boxplot of species richness measurements by investigator and participants in Slugs Count (n = 57), with minimum and maximum (whiskers), median (dark line inside box), first quartile and third quartile (lower and upper box boundaries), and open circles indicating outliers.

out of five, indicating high levels of confidence in scientific ability. However, questions related to applying this knowledge in relation to the Slugs Count project averaged a mean score of 3.74 out of five.

No significant differences were found between questions on general scientific understanding and following instructions for the Slugs Count project, or understanding scientific topics and identifying slugs well in comparison to others within the participant's age groups (Table 6). However, significant differences were observed in scores between statements on understanding general science topics and understanding how to identify slugs, and personal confidence in explaining general science topics to others and explaining how to identify slugs to others. The direction of these differences indicates that understanding and explaining slug identification is significantly more difficult than understanding and explaining general science topics.

3.6 | Improvements in accuracy over time

Grouping participants overall misidentification scores by prior experience level indicated that there may be some effect of experience (Figure 6). However, a Kruskal–Wallis chi-squared test indicated the differences between the groups was not significant, χ^2 (2 df, N = 57) = 3.30, p = 0.19, therefore prior experience is not a good predictor of an individual's accuracy in identifying slugs to species.

Plotting individual survey misidentification proportions over time by experience level revealed a complex trend (Figure 7), with a wide range of variation around the mean in all groups, but a slight

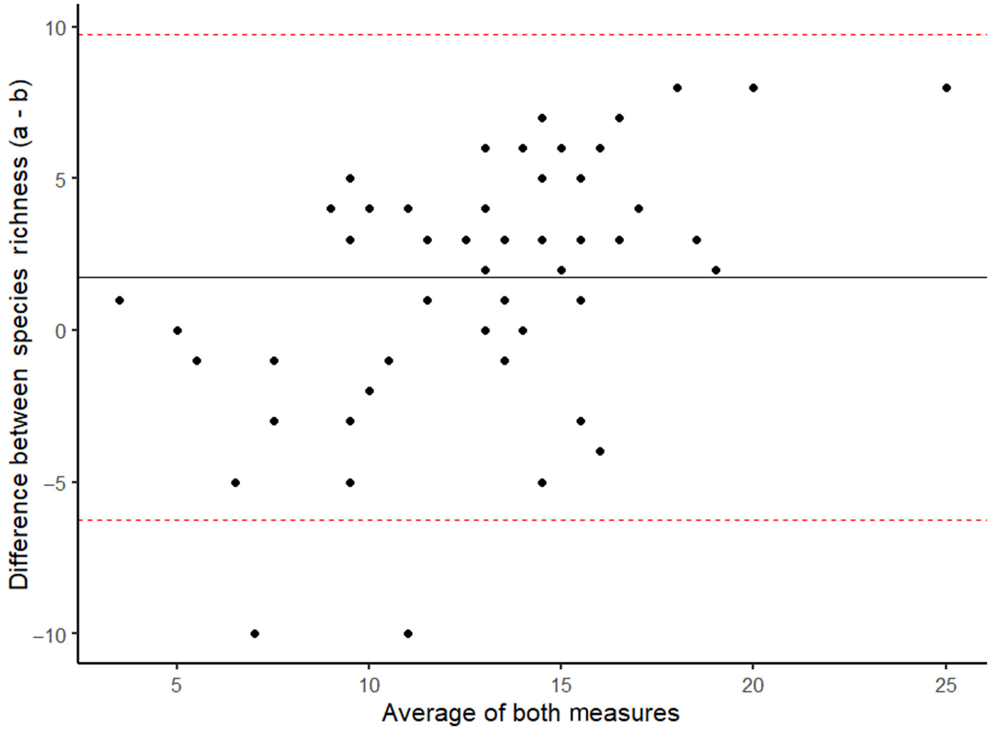

FIGURE 3 Bland–Altman plot of differences between species richness measurements (a) participant's and (b) investigator's ($n = 57$), with mean difference (black line) and 95% confidence limits (red dashed lines).

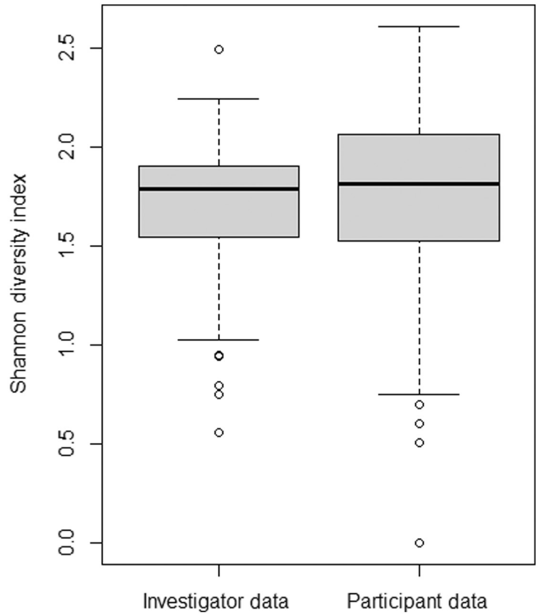

FIGURE 4 Boxplot of Shannon Diversity Index (*H*') estimates for all sites based on abundance measures of species made by investigator and participants in Slugs Count ($n = 57$).

overall trend of improvement in accuracy over time for all participants. One large outlier was removed from the plot with a score of 6.0, as the large difference was due to slugs decaying in the post before the participant's identifications could be verified. Other outliers and scores over 1.0 were also a consequence of the slug samples decaying before identification was possible, or occasions where no identifications were attempted by the participant.

There was a slight increase in accuracy across all experience groups over time (Figure 8). Participants with more prior experience of slug identification were mostly more accurate, but on some occasions were less accurate than the beginner and the group with no previous slug identification experience. However, all experience level groups showed a large amount of deviation around the mean identification score, indicating a high level of variation between individual participants within these groups.

To test the hypothesis that the number of surveys completed and previous slug identification experience influenced accuracy, survey number was used as a proxy for time, and identification experience was used as a grouping factor in the model. Any data points over 1.0 ($n = 14$) were excluded from analysis, as they represented events where identifications were not attempted or specimens were lost in the post. Participants who found no slugs during any of their surveys were also excluded from this analysis.

Modelling the influence of survey number and previous slug identification experience on misidentification scores (Table 7) with individual surveyor as a fixed effect indicated that only survey number had a significant effect. No significant interactions were found between previous slug identification experience and survey number, indicating that prior slug identification experience did not have a significant effect on the reduction in slug misidentification scores as the number of sampling occasions increased. However, surveyor

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TABLE 5 Two-sample Paired Sign Test results for questions on skills prior to and after participation in the Slugs Count project (*n* respondents = 55).

Question subject: "I have the skills necessary to.:"	Median score (before)	Median score (after)	*p* value	Dominance statistic	Overall direction of change
Successfully submit slug observations	3	5	<0.001	−0.782	Increase
Understand collection protocols	3	5	<0.001	−0.764	Increase
Collect data in a standardised manner	3	5	<0.001	−0.709	Increase
Closely observe and record slugs	2	4	<0.001	−0.855	Increase
Accurately identify slugs	2	4	<0.001	−0.818	Increase

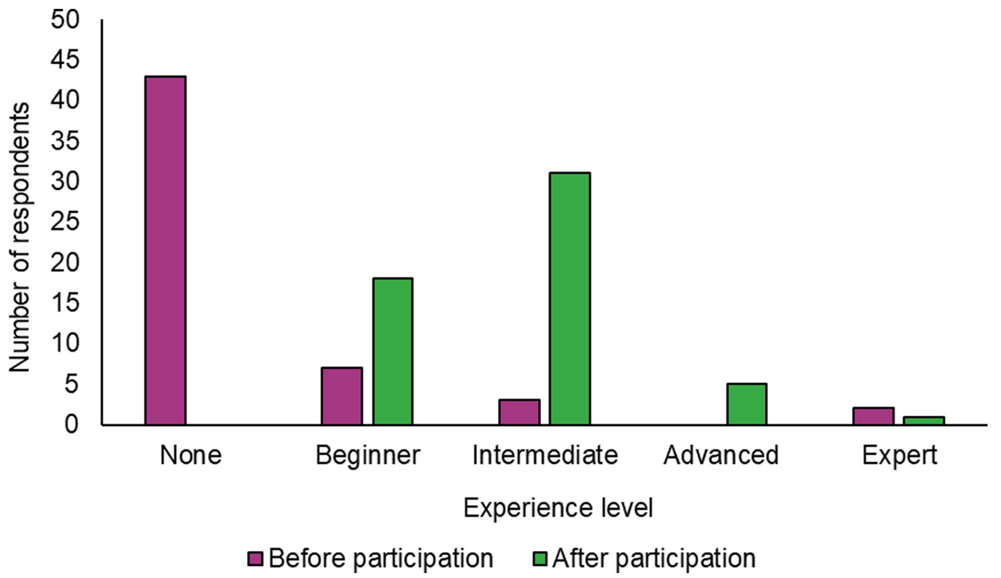

FIGURE 5 Self-described experience level in identifying slugs to species before and after participating in the Slugs Count project (number of respondents = 55).

name resulted in a relatively large random intercept variance (τ00 0.81), indicating that the individual observer likely has a larger effect on accuracy, rather than grouping by prior experience.

3.7 | Participant retention and engagement

Over 98% of participants attended live (51, 92.7%) or watched the recordings of the online training sessions (3, 5.5%) offered at the beginning of the project on the project aims, survey methodology and slug identification training. Over 84% of participants also attended catch up sessions (30 attended live sessions, 16 watched recordings), which took place 8 months in to the 12 month collection period. There was a very high level of retention in participation through the project with just one participant leaving the project before the first survey occurred. A further two participants left the project before it ended.

Forty-six participants (77%) of the 60 selected successfully completed all 13 scheduled surveys, and nine participants (15%) completed 12 of 13 scheduled surveys. In total 727 out of a possible 780 surveys were completed, representing a 93% completion rate. Over time the number of surveys completed remained high, with slightly lower participation in surveys three and four, and completion rates declining gradually from survey eight onwards (Figure 9).

In the project evaluation survey, the majority of participants (52, 95%) reported that they enjoyed participating in the project (Table 8) and identifying slugs (52, 95%), as well as the project changing their interest in slugs (50, 91%). However, there was a lower level of interest from participants in continuing to record slugs outside of the Slugs Count project (36, 66%).

4 | DISCUSSION

Citizen science can be used in a wide range of projects ranging from large-scale and long-term to short-term, more focussed approaches (Gardiner & Roy, 2022). In addition to generating scientific data these projects can have impacts on the people involved, improving their connection with the natural world (Pocock et al., 2023). In the present study we used a structured survey approach to generate high-quality data about slug species

TABLE 6 Sign test results for evaluation of learning and doing science self-evaluation questions with dominance statistic and direction of difference indicated (*n* responses for each statement = 55).

Statement 1	Mean score Q1	Statement 2	Mean score Q2	Sign test *p* value	Dominance statistic	Direction of significant difference
"I think I'm pretty good at understanding general science topics."	4.33	"I think I'm pretty good at following instructions for slug identification as part of Slugs Count."	4.09	0.06	0.18	NA
"Compared to other people my age, I think I can quickly understand new science topics."	4.05	"I think I'm pretty good at following instructions for slug identification as part of Slugs Count."	4.09	0.83	−0.04	NA
"Compared to other people my age, I think I can quickly understand new science topics."	4.05	"Compared to other people my age, I think I can identify slugs pretty well."	3.98	0.83	0.03	NA
"It takes me a long time to understand new science topics."	4.00	"It takes me a long time to understand how to identify slugs."	3.31	<0.001	0.455	Decrease
"I feel confident in my ability to explain science topics to others."	4.00	"I feel confident about my ability to explain how to identify slugs to others"	3.56	<0.001	0.382	Decrease

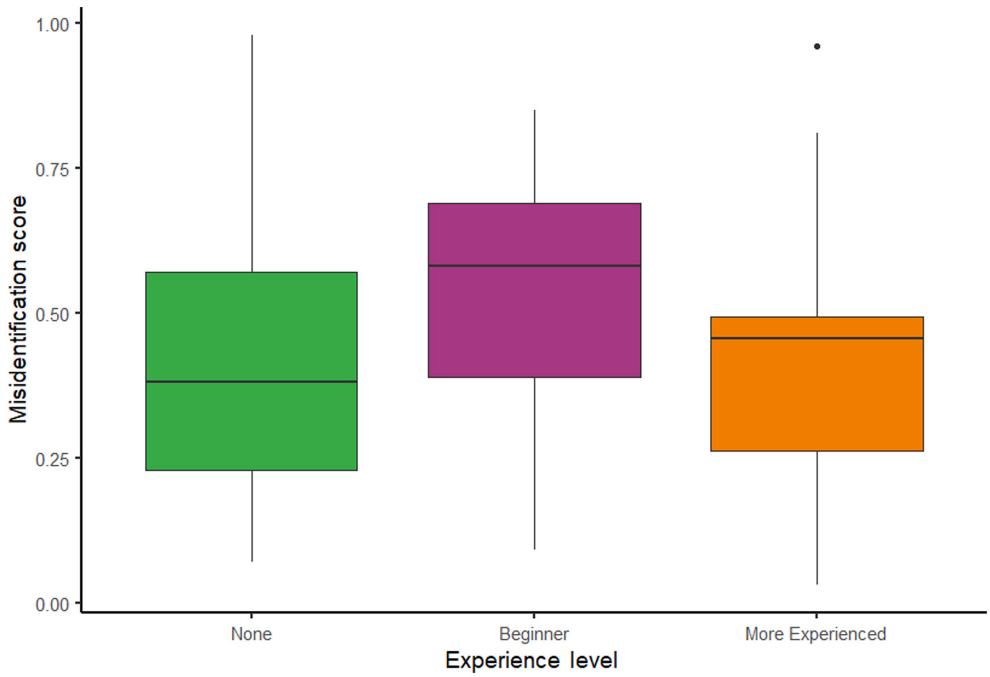

FIGURE 6 Proportion of slug misidentifications, grouped by the experience (none, beginner, more experienced) in slug identification of the participants.

diversity in gardens and to assess the engagement from participants. Citizen science provided an effective approach to assess slug diversity across widespread geographic locations throughout a full year of sampling. Despite the complexity of the Slugs Count protocol, there was a high level of engagement throughout the study, and the resulting high-quality dataset contributes hugely to our understanding of the current status of slugs in British gardens. Participants suggested that their scientific skills had improved through involvement with the project, and it is known that there are wider benefits of nature connectedness (Butler et al., 2024; Pocock et al., 2023), although these were not measured in the current project.

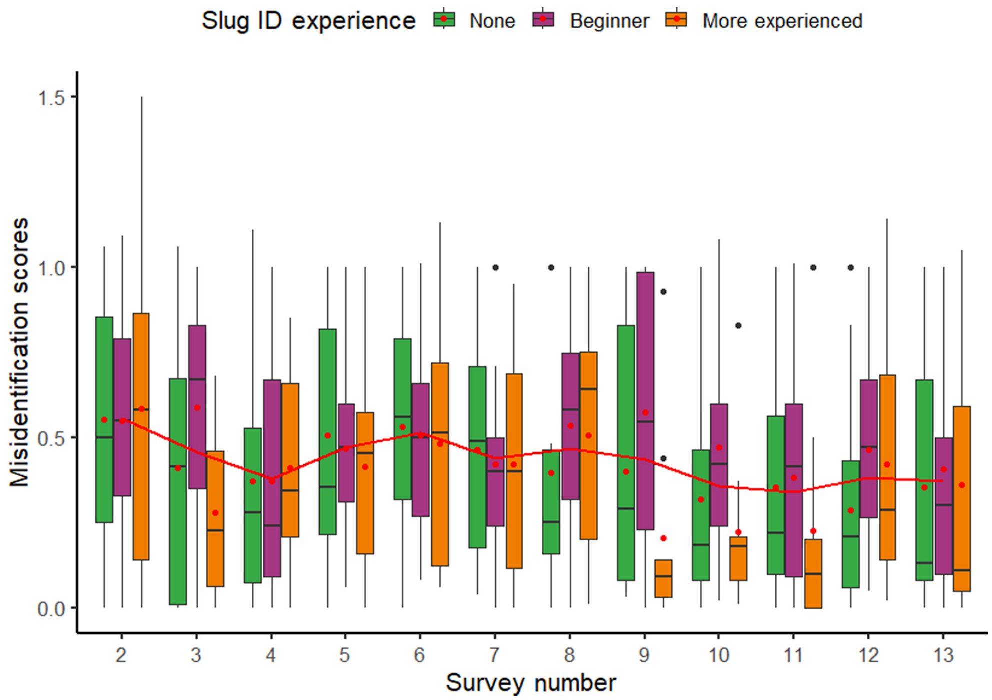

FIGURE 7 Misidentification proportions per consecutive survey in Slugs Count, grouped by previous slug identification experience; no experience (green, $n=24$), beginner experience (purple, $n=21$), and more experienced (orange, $n=12$). The red line indicates mean misidentification score for all experience levels combined per sampling occasion. Red dots indicate the mean misidentification score per experience group.

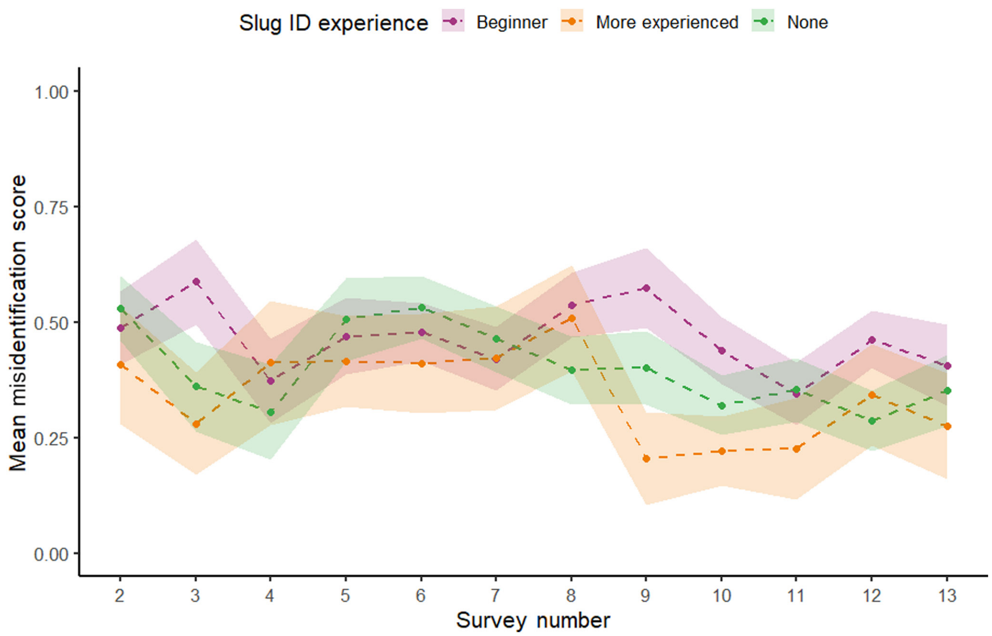

FIGURE 8 Mean proportion of misidentifications per consecutive survey, grouped by prior slug identification experience in Slugs Count participants; no experience (green, $n=24$), beginner experience (purple, $n=21$) and more experienced (orange, $n=12$). Shaded areas indicate standard deviation around the mean for each group.

4.1 | Accuracy; measuring slug abundance

Abundances of slugs recorded by participant and investigator were significantly different, with participants likely to record larger numbers of slugs. Some underestimates were also noted, the majority of which were occasions where participants did not count slugs before sending them in. Transport and storage of samples likely caused some difference in abundance measures as conditions while the parcels were in

Predictors	ID accuracy score Odds ratios	CI	*p*
(Intercept)	1.50	0.63–3.57	0.361
Survey number	0.91	0.83–1.00	**0.045**
ID XP [more experienced]	0.80	0.18–3.67	0.778
ID XP [none]	0.61	0.19–2.03	0.424
Survey no. * ID XP [more experienced]	0.94	0.79–1.12	0.499
Survey no. * ID XP [none]	1.00	0.88–1.14	0.955
Random effects			
σ2	3.29		
τ00 Surveyor name	0.81		
ICC	0.20		
N Surveyor name	57		
Observations	544		
Marginal R^2/conditional R^2	0.047/0.236		

TABLE 7 Binomial mixed effect generalised linear model output for the influence of sampling experience (survey number) and the interactions with prior slug identification experience (ID XP) on participant's slug identification accuracy scores, with individual surveyor as a fixed effect. *p* values < 0.05 are in bold.

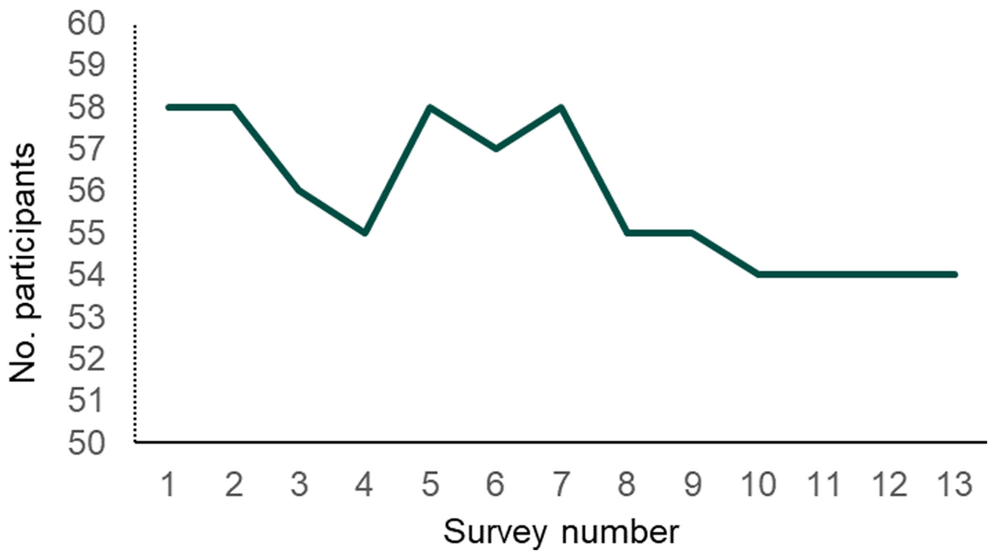

FIGURE 9 Number of participants ($n = 60$) completing each of the 13 scheduled Slugs Count surveys, note that the *y* axis starts at 50.

transit could not be monitored, and a small number of parcels never arrived or were delayed in the post. While the time spent in the post was monitored for many samples, this data was not consistently recorded enough for analysis of the potential impact on slug abundance. Upgrading to a next-day delivery service may have prevented many of these losses, but would have increased project cost. Receiving slugs from participants cost approximately £3720 in postage, not including the costs of sending out additional materials.

4.2 | Accuracy; measuring species richness

Species richness recorded by participants was significantly higher than that of the investigator. This is not uncommon in citizen science projects involving species identification, where over-reporting of rare species and under-reporting of common species can occur (Gardiner et al., 2012; Roy et al., 2016). This was also observed in Slugs Count, with ancient woodland specialist *Limax cinereoniger* incorrectly reported by nine individual participants.

Participants were most likely to underestimate species richness in early surveys, but slightly over estimate species richness in later surveys as confidence in identifying slugs increased. Previous citizen science studies of invertebrates have found a positive correlation between how frequently species were encountered by an individual and identification accuracy (Gardiner et al., 2012). Some slug species are seasonal in maturity and abundance, so the rate at which identifications increased in accuracy may be related to participants encountering new species in their surveys.

The plasticity of slug species' colouration in response to environmental conditions and genetic variation may lead to some inaccuracies

TABLE 8 Responses from Slugs Count participants to project evaluation questions on project enjoyment and interest levels in slugs after the project (*n* respondents = 55).

	Level of agreement				
Question subject	Not at all	Not much	Neutral	Somewhat	Very much
Enjoyed participating in project	0	0	3	6	46
Enjoyed identifying slugs	1	1	1	6	46
Changed interest in slugs	1	1	3	15	35
Want to continue recording slugs	11	2	6	19	17

as some individuals may not be typical in appearance. This was noted in the material received, with some *Deroceras reticulatum* slugs uncharacteristically dark in colouration causing uncertainty in participant identifications. Initial identification support was required from a taxonomic expert to assist the participant in recognising the other characters that identify which species atypical specimens belong to.

4.3 | Accuracy; estimating species diversity

Participants' measurements significantly over estimated species diversity in the project. This indicates that participants over-recorded rare species in their samples, likely due to misidentification of common species. However, it may also reflect the inclusion of some species aggregates within the data. For example, participants were advised that *Ambigolimax nyctelius* (Bourguignat, 1861) and *Ambigolimax valentianus* (A. Férussac, 1821) should be recorded as *Ambigolimax* sp., due to an accurate separation to species not being possible without dissection. However, the identification guide provided did not make this clear, and it was observed that several participants would record these slugs to species, rather than genus, which will also have contributed to overestimates of species diversity. Slugs may be a particularly challenging taxon for citizen scientists from this aspect, due to the relatively high proportion of aggregate or cryptic species.

A particularly delicate slug species, *Boettgerilla pallens* (Simroth, 1912), was occasionally recorded by participants but did not always arrive in the laboratory, so may be under-represented in the investigator's species diversity measures. *B. pallens* is a distinctive slug species, so should be easily identifiable by participants. Participants who received identification feedback excluding this species after having sent it in were able to confirm this species was present by providing photos, indicating that this species was being found and accurately recorded. Therefore, the poor transportability of some slugs may have contributed in part to lower estimates of species diversity by the investigator. Some species of slugs are known to be cannibalistic (Rollo & Wellington, 1979), and some losses may have occurred due to this behaviour.

Collecting a larger number of citizen science samples than would be chosen for traditional field sampling methods has been suggested as an option to reduce the influence of volunteer error (Gardiner et al., 2012). Therefore, the effect of inaccuracies in estimating species diversity could have been reduced by increasing the amount and frequency of samples taken by individuals. However, this also needs to be balanced with project resources, as sampling was at maximum capacity in terms of time and resources available.

4.4 | Improvements in accuracy over time

As expected, slug identification accuracy improved over time. However, prior slug identification experience showed no significant effect on accuracy over time, with more experienced participants misidentifying slugs at a similar rate to those with limited or no previous slug identification experience. This is in direct contrast to the findings of citizen science project eBird, which found that the experience level of observers consistently results in greater accuracy (Hochachka et al., 2012). However, it supports the community consensus that slugs are challenging taxa to identify to species level, even for those with prior experience.

At the beginning of the Slugs Count project, rates of accuracy ranged between 47%–56%, improving to 59%–70% accuracy by the end of the project. Rates of 70%–90% accuracy have been reported for species identifications across a diverse range of taxa in citizen science projects (Kosmala et al., 2016; Perry et al., 2021). A citizen science project in Switzerland on the species *Arion vulgaris* found that 92% of specimens identified and provided by participants were confirmed by DNA barcoding as the target species (Dörler et al., 2018), showing that a high level of accuracy is possible for a single species survey.

Training and engagement have been shown in other citizen science projects to be essential in ensuring quality of data, with ongoing feedback increasing accuracy and retention (Kosmala et al., 2016). It is difficult to quantify what effect maintaining regular contact and providing identification feedback had on improving participant accuracy over time within the Slugs Count project. However, comments from participants indicated that many individuals found the feedback on identifications useful for maintaining enthusiasm, recognising where they may be making mistakes, and also increasing confidence in their own slug identification abilities.

4.5 | Participant retention and engagement

The Slugs Count project was successful in maintaining a high level of participation throughout, showing that citizen science projects of complexity can retain interest while generating large amounts of valuable data. Combined with other successful examples of hypothesis-led citizen science projects covering invertebrate taxa (Pocock & Evans, 2014; Roy et al., 2016), this provides evidence that the approach can be a powerful tool in monitoring species diversity for invertebrate taxa across Britain. Over 65% of respondents were interested in continuing to submit records of slugs once the project came to an end, illustrating how projects of this type can increase the number of people submitting data for under-recorded taxa past the scope of the initial project. However, the lower rate of interest in continuing to record slugs after the project in comparison to overall enjoyment of taking part may be due to the perceived difficulty in identifying slugs to species level that participants reported. Comments from participants via correspondence throughout the project showed that identifying slugs to species was time consuming and found to be challenging by many. However, this could be mitigated by introduction to national recording schemes, ongoing engagement from these schemes, and continued tailored support from experienced verifiers.

4.6 | Participant's self-described development

There was a small intentional selection bias towards participants with prior experience of identifying slugs, as a suitable sample size of experienced participants was needed to measure the improvement in identification skills against by those with no experience. Between 70% and 80% of respondents to the evaluation survey reported significant perceived increases in scientific skills from participating in the Slugs Count project. General scientific understanding appeared to have little effect on the ability to understand and follow protocols and participate in the Slugs Count project. However, significant differences were observed between general scientific understanding and the confidence of participants in identifying slugs to species, and explaining to others how to identify slugs. This provides evidence that slugs are a challenging group to identify to species level by citizen scientists.

Self-described experience level in slug identification increased significantly for the majority of project participants, with only one individual reporting a decrease in skill level. The majority of participants came to the project with little to no experience of slug identification, therefore an increase of skill was anticipated. The rate of increased skill level was greatest for those who entered the project with no slug identification experience, with an average increase of 1.63 skill levels. However, the rate of increase was much less for those with previous intermediate to expert experience of slug identification, with an average increase of 0.2 levels.

As the evaluation survey was anonymized due to data protection and ethical requirements, it is not possible to compare actual misidentification scores with perceived increased skills in slug identification. However, the reduction in misidentification scores as the project progressed indicates that increased confidence in skills is likely to have been supported by increasing accuracy.

Demographics have not been included within this analysis. However, there is some evidence that age and education level of participants can have an effect on the ability of volunteers to accurately identify organisms (Delaney et al., 2008). As demographic data was gathered anonymously, it is not possible to compare misidentification scores between these demographic groups. However, it may be worth considering these differences in future citizen science studies involving assessing participant accuracy in identifying organisms.

5 | CONCLUSIONS

The Slugs Count project demonstrated that citizen science projects involving identification can successfully generate large amounts of good quality data, while also being highly enjoyable for participants. Participants were found to overestimate slug abundance and species richness, which led to higher measurements of species diversity than those calculated from verified data. This illustrates the importance of verification in citizen science projects, particularly if the data are used to answer hypothesis-driven questions on species ecology and distributions (Hochachka et al., 2012; Roy et al., 2016). However, some of these differences in abundance estimates could have been driven by the losses of live specimens while in transit to the investigator. Accuracy of slug identifications increased significantly over time, both in quantitative measurements and qualitative measurements of participants' own experiences. This was despite participants finding slugs a challenging taxa to identify with confidence. Self-defined prior slug identification experience was found not to be a reliable predictor of accuracy, as participants may have different perceptions of these categories and over- or under-estimate their own experience and abilities. Continued engagement through feedback and training from experienced naturalists or professional scientists to participants is essential for retaining citizen science participation in a project of this type. However, regular monitoring of slugs in gardens by citizen scientists is important for understanding changes in this dynamic fauna. With careful planning and preparation citizen science approaches can be very effective, even with taxon groups that are challenging to identify. With training and support throughout the project it is possible to achieve high levels of participant retention, even with a demanding protocol and study taxon.

AUTHOR CONTRIBUTIONS

Imogen Cavadino conceived the ideas and designed methodology with input from all other authors; Imogen Cavadino collected and managed the citizen science data collection, analysed the data, and led the writing of the manuscript. Imogen Cavadino and Gordon Port lead revising the manuscript in response to peer review. All

authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

Helen Roy is an Associate Editor for the journal *People and Nature* but was not involved in the peer review and decision making process. The remaining authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

Data supporting this study will be available from DRYAD following a 12 month embargo. The verified data on slug species occurrences is available via the NBN atlas and GBIF: Royal Horticultural Society (2023), RHS Slugs Count. https://doi.org/10.15468/qr5d26.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supplementary Material 1. Slugs Count; application screening questions.

Supplementary Material 2. Training session slides.

Supplementary Material 3. Slugs Count participants evaluation survey questions.

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