Citizen scientists' motivation to participate in environmental DNA (eDNA) surveys: A case study on monitoring mammals in the UK

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Abstract

1. Citizen scientists have become integral participants in nature conservation projects, and the demand for effective conservation efforts has sparked increasing interest in utilizing environmental DNA (eDNA) for species monitoring, drawing citizen scientists into the sample collection process. However, there is still a gap in understanding the motivations behind volunteer engagement in eDNA projects. This includes the need to validate the data retrieved from collected samples and recognise the value of volunteer involvement to ensure their satisfaction and active engagement.
2. To address this gap, we trained conservation volunteers to collect eDNA samples from two rivers and a beaver enclosure for detecting terrestrial and semi-aquatic mammals. Two questionnaires were distributed before and after sampling to gather insights about volunteer science capital, motivation to participate and their experiences during eDNA sampling.
3. Citizen scientists were highly motivated to participate, developed innovative approaches to collect eDNA samples and showed a strong understanding of eDNA surveying techniques. Overall, citizen scientists expressed high science capital, which facilitated their enjoyment in contributing to meaningful scientific knowledge, helping their local wildlife, and expressing a desire for continuous learning. Additionally, concerns were made about plastic usage in eDNA studies, highlighting the need to address these environmental considerations. These findings highlight the broader impact of citizen science, extending beyond scientific outcomes alone.
4. A greater number of mammal species overall and between the sampling sites were detected by citizen scientists compared to the eDNA researchers. Their valuable contributions and local knowledge of the sampling sites have enhanced the scientific endeavour and expanded our understanding of local biodiversity.

5. This study provides insights into the feasibility and benefits of involving citizen scientists in eDNA surveys for both advancing conservation efforts and acknowledging the values of volunteers. We provide a robust comparison of results and highlight the benefits of volunteer participation, including increased knowledge exchange and enjoyment of biodiversity monitoring and conservation. The eDNA results were shared with the volunteers, leading to meaningful discussions about the species detected and their implications for conservation efforts. This collaborative approach encouraged knowledge exchange and further engagement between researchers and citizen scientists.

Keywords

Biodiversity, Conservation, Citizen science, Metabarcoding, Science Capital, Volunteer Motivation

Introduction

Biodiversity is declining worldwide due to the rapid increase in anthropogenic pressures (Brauer and Behereharay, 2020). This loss highlights the need for effective species monitoring to understand and mitigate these declines (McCallum, 2015). Citizen scientists contribute their spare time to observe and identify biodiversity, generating data used for species distribution assessments, and expanding research and action in ecology and conservation (Chandler et al, 2017; Soteropoulos et al. 2021). Citizen science (CS) is a term that describes scientific contributions to research carried out by volunteers, typically in collaboration with scientists (Eitzel et al. 2017; Hacklay et al. 2021). We use the term CS to denote our form of contributory science, while also acknowledging that there are different types of community-based projects (Shirk et al. 2012; Cooper et al. 2021; Hunter et al. 2023).

Citizen Scientists' Motivations and Science Capital

CS projects help advance scientific knowledge by addressing challenges associated with collecting large amounts of data over broad geographical scales that would be otherwise unattainable (Dickinson et al. 2010, 2012). This also offers numerous benefits to citizen scientists, such as connecting people with nature, engaging with the community, learning opportunities, and increased awareness of the importance of local biodiversity (Bonney et al. 2016; Geoghegan et al. 2016; Walker et al. 2021; West et al. 2021). Understanding why volunteers contribute to CS projects requires identifying their primary motivations, which can be categorised as intrinsic, such as a genuine interest in helping wildlife or advancing science (Bruyere and Rappe, 2007); Raddick et al. 2013), or extrinsic, such as advancing in a career or for personal growth (Clary et al. 1992; West et al. 2021).

Understanding the motivations driving volunteers' participation in CS projects involves acknowledging the link to science capital (Edwards et al. 2018). Science capital represents the accumulation of science-related knowledge, attitudes, experiences, and resources that individuals acquire throughout their lives (Archer et al. 2015). It can be measured by assessing individuals' scientific literacy, and exposure to science-related media and participation in science-related activities (Archer et al. 2015; Jones 2021, 2022). However, it has not been extensively measured for adults (Kaakinen et al. 2023). Science capital plays an important role in shaping individuals' involvement in science-related activities and their overall understanding and appreciation of science (Bourdieu 1984; Archer et al. 2015). By assessing the science capital levels of volunteers, researchers can gain insights into whether certain demographics or communities with lower science capital are underrepresented in the project (Edwards et al. 2018). Participating in CS projects has the potential to enhance individuals' science capital by expanding their scientific knowledge and skills, particularly in relation to newer methodologies (Edwards et al. 2018). Recognising and understanding individuals' science capital is important for adapting the educational and learning aspects of the project in order to improve volunteer retention (Gold & Ochu, 2018).

Engaging Citizen Scientists in eDNA-Based Monitoring

Environmental DNA (eDNA) metabarcoding is a non-invasive, and cost-effective method for rapidly assessing biodiversity (Valentini et al. 2016). Environmental samples (e.g., water, soil, or air) are collected and species' DNA is extracted, analysed, and then multiple species can be identified simultaneously using next-generation sequencing (Pawlowski et al. 2020). eDNA metabarcoding has proven to

be particularly effective in detecting and monitoring terrestrial and semi-aquatic mammals (e.g. Sales et al. 2020; Broadhurst et al. 2021). With the simplicity and speed of collecting environmental samples, eDNA offers an exciting and valuable opportunity for citizen scientists to contribute to rapid biodiversity assessments (Biggs et al. 2015).

Citizen scientists have contributed to eDNA surveys by assisting in the collection of eDNA samples from aquatic habitats (Biggs et al. 2015; Buxton et al. 2018; Larson et al. 2020; Agersnap et al. 2022; Suzuki-Ohno et al. 2023; Meyer et al. 2021). Previous studies have shown that it is feasible to include volunteers in eDNA surveys with limited training (Biggs et al. 2015), and enhance volunteer understanding of biodiversity, ecosystems and eDNA (Suzuki-Ohno et al. 2023). Some challenges have been identified, with citizen scientists facing difficulties in selecting appropriate sampling sites and understanding species names when presented with the results (Suzuki-Ohno et al. 2023). These findings contribute to the ongoing efforts to improve CS initiatives and enhance the quality and effectiveness of volunteer education.

To ensure the successful involvement of citizen scientists in eDNA surveys, it is essential to assess the scientific and social aspects of the project. This entails recognising the benefits and values for volunteers while advancing conservation efforts and scientific knowledge (Rotman et al. 2012). However, there exists a noticeable gap in eDNA CS research regarding the understanding of factors that motivate volunteers to engage in eDNA surveys and their personal experiences with eDNA data collection.

To address these gaps, our study incorporated the European CS Association's (ECSA) 10 principles of CS into the research objectives (Pocock et al. 2014; Robinson et al. 2018; Haklay et al. 2020). To support the integration of these principles into our

study, we conducted two surveys, one before and one after eDNA sampling to investigate the citizen scientists' motivation for participating, science capital level and their overall experience with eDNA sampling. To enhance citizen scientists' skills and knowledge in eDNA monitoring, we provided an educational and interactive training workshop which was designed to facilitate collaboration between researchers and citizen scientists. Additionally, we evaluated the effectiveness of their eDNA surveying efforts by comparing results obtained by citizen scientists and researchers. A further workshop was conducted to openly share the results with the citizen scientists, and to provide feedback to volunteers, acknowledging their valuable contributions. The workshops and combined quantitative and qualitative analysis not only help to improve our understanding of the volunteers' experience of eDNA sampling but to also provide context and opportunities for mutual learning between the researchers and citizen scientists (Rüfenacht et al. 2021).

Methodology

Study Area

Our study area is in Essex, England, along the rivers Colne and Blackwater and a beaver enclosure at Spains Hall Estate. Previous research in this area used eDNA metabarcoding to measure the diversity and distribution of semi-aquatic and terrestrial mammals and detected 25 of the 28 species that are known to occupy the sampling area (Broadhurst et al. 2021). Drawing upon our understanding of the species present in the sampling area and our familiarity with the sampling sites, we were able to actively engage citizen scientists in eDNA surveying.

Ethics statement

Our study received ethical approval (Ref. 210) from the University of Salford Ethics Committee on 27th October 2021 and was conducted in accordance with the University's Governance Framework. Volunteers gave informed consent through a signed form, ensuring the confidentiality of sensitive information and photographic evidence (Appendix 2). Survey responses were voluntary and anonymous, with no compulsory questions.

Procedure for citizen scientists

A five-phase framework was designed to guarantee thorough planning, discussions and firsthand training for every volunteer (Fig. 1). Before the start of the project, the researchers and Essex Wildlife Trust (EWT) staff designed and planned the project (Fig. 1A). An eDNA training workshop was conducted on 15th November 2021 at Abberton Reservoir (The Rows, Colchester, CO2 0EU; Fig. 1B and 2A). The workshop aimed to provide detailed information on how eDNA surveys work, share results from the same area (Broadhurst et al. 2021), and train the volunteers in eDNA sample collection and filtration techniques (Fig. 1B). Following the workshop, eDNA data collection was conducted (Fig. 1C) and the researchers carried out laboratory work (Fig. 1D). The results of the project were shared with the volunteers during a workshop (Fig. 1E).

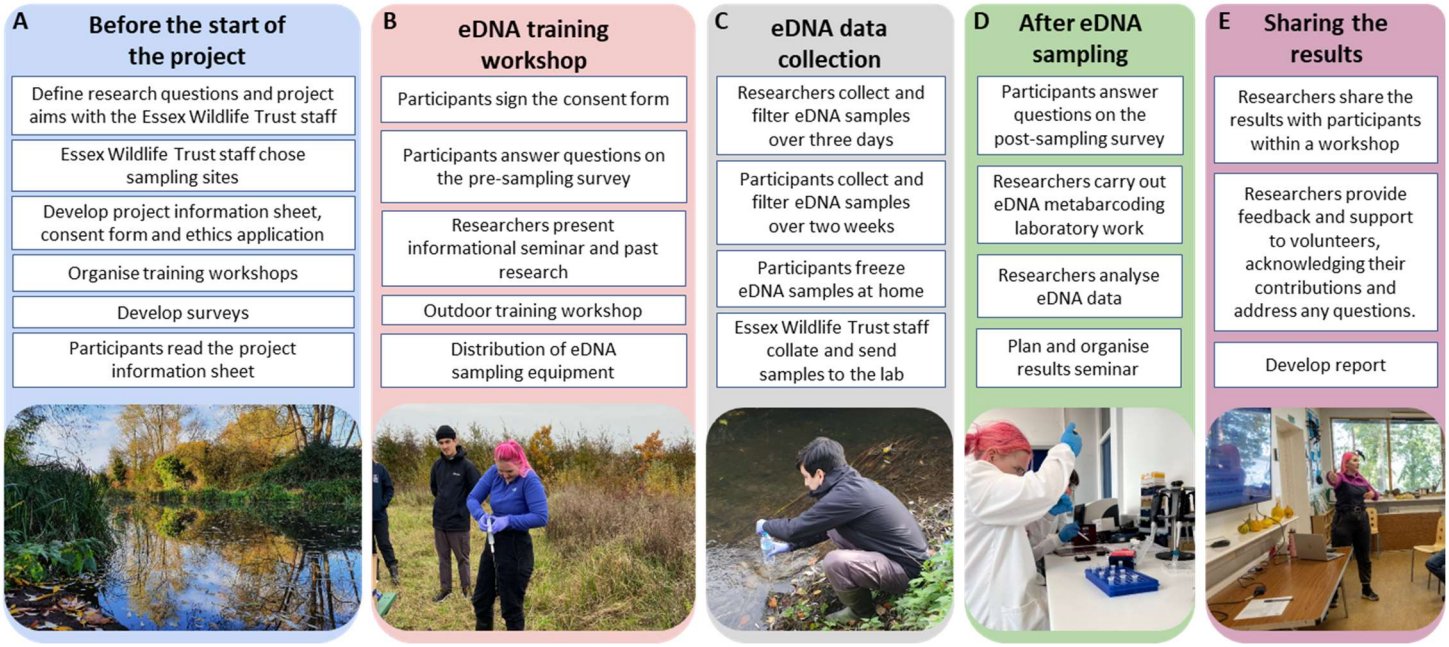

Figure 1. Workflow of the scientific process

Pre-sampling survey

The first survey (called pre-sampling survey hereafter) was conducted at the start of the workshop, after the volunteers had reviewed the information sheet and signed the consent form but before the informational seminar, outdoor workshop and the eDNA sampling (Fig. 1B). The sequence of events was implemented to ensure that the motivations of the citizen scientists were not influenced by the subsequent activities during the workshop. Volunteers were given the choice to respond to the questions either on paper or online, providing flexibility and accommodating individual preferences.

The pre-sampling survey included 13 questions, covering volunteer demographics (age, gender, level of education, ethnic group; and physical or mental health conditions; Table S2), previous volunteering experiences, and their related skills or knowledge. Volunteers rated their level of agreement with 13 motivational statements (Table S4, West et al. 2021) and eight statements on science capital (Archer et al.

2015; Table S5) on a Likert scale (Likert, 1932). Ratings ranged from 1 (strongly disagree) to 5 (strongly agree). The final three questions assessed volunteers' familiarity with eDNA, informing the planning of the training event to ensure accessibility and engagement. Volunteers were asked about their prior experience with eDNA, including awareness of eDNA surveys and previous involvement in sampling (Table S5).

eDNA sample collection

The volunteers selected one or multiple sites along the rivers (sites C1- C15, B6 - B14, Fig. 2A), and inside and downstream from the beaver enclosure (B2, B4, B5, Fig. 2B). The corresponding geographical coordinates for each location were provided using what3words (London, UK; https://www.what3words.com). The researchers collected the eDNA samples over three days (16th – 18th November 2021), while the volunteers had the flexibility to collect their samples at any time over a two-week period (16th - 30th November 2021), reflecting what would typically happen in a citizen science survey involving multiple volunteers (Maund et al. 2020).

The sampling procedure followed protocols described in Broadhurst et al. (2021). Five 500 ml eDNA water replicates were collected from each of the sampling sites along the rivers, by both volunteers and researchers. Researchers collected five water replicates from each of the four sites inside and downstream from the beaver enclosure (B1 – B4) and ten replicates were collected from a large pond inlet of a brook (B5; Fig. 2B). Volunteers collected five water sample replicates from one site inside the beaver enclosure (B2), downstream from the beaver enclosure (B4) and from the large pond inlet (B5). The additional sampling locations and replicates at these sites were collected opportunistically by the researchers in order to answer

further questions on the development of the beaver enclosure not related to this study. Six field controls were collected by researchers, consisting of a bottle of distilled water (500 ml) opened briefly at the beginning and end of each of the three sampling days to test for field contamination. Volunteers stored the filters in a freezer at their homes until the samples were collected by the EWT staff. Samples were kept frozen and then transported to the laboratory at the University of Salford using courier services. Overall, researchers collected 150 eDNA water sample replicates from 24 locations and volunteers collected 135 eDNA water sample replicates from 22 locations.

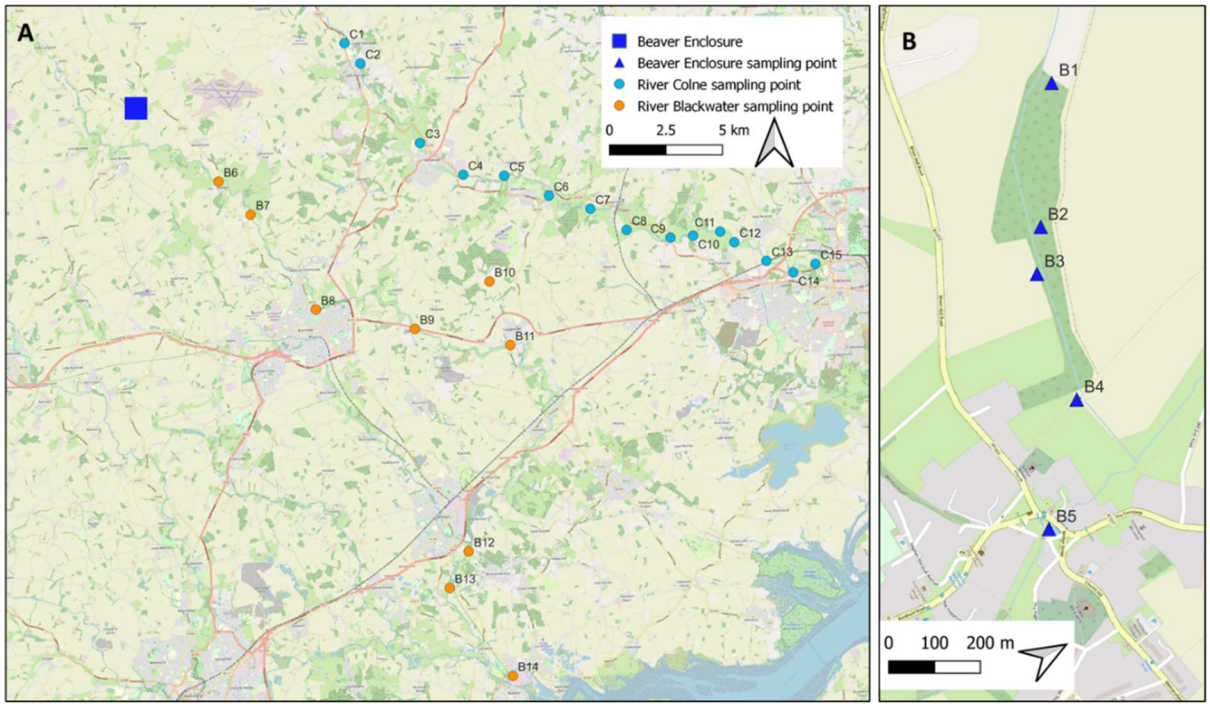

Figure 2. Environmental DNA (eDNA) sampling locations in Essex along the river Colne (A; C1-C15), river Blackwater (A; B6-B14) and inside and downstream of the beaver enclosure (B; B1 – B5).

eDNA laboratory methods

DNA extraction, metabarcoding and bioinformatics analysis followed methods described by Broadhurst et al. (2021) and a complete description of each step is provided in Appendix S1. Briefly, DNA was extracted from the filters in a dedicated eDNA laboratory, following the Mu-DNA water protocol (Sellers et al. 2018). Six DNA extraction negative controls (one for each day of extractions) containing only extraction buffers were included. eDNA was amplified using the MiMammal 12S primer set (Ushio et al. 2017). A total of 285 eDNA samples, including field collection blanks (12), laboratory negative controls (32, including 16 DNA extraction blanks and 16 PCR negative controls) and positive control (12, Northern muriqui *Brachyteles hypoxanthus* faecal DNA samples at a concentration of 0.05 ng/μL) were distributed across four sequencing libraries. The final pool was sequenced on a single Illumina MiSeq run at 18 pM concentration for 2x150-bp paired-end sequencing using an Illumina v3 600 Reagent kit (Illumina, San Diego, CA, USA). Sequence reads from the four libraries were analysed separately using the OBITools metabarcoding package (Boyer et al. 2016) and conservative filtering steps were performed in R v.4.0.2 (R core team, 2022) to identify and exclude sequence reads originating from tag switching and cross-contamination in order to avoid false positives (Appendix 1).

Post-sampling survey

The second survey (called post-sampling survey hereafter) was conducted after the volunteers had taken part in eDNA sampling using a web-based platform (Microsoft Forms, Fig. 1D). The post-sampling survey included 13 questions (Table S3). Volunteers reported the number of sampling sites they visited and responded to a series of open-ended questions aimed to capture their reflections on the eDNA

sampling process. This included the aspects of the sampling that were successful to them, how they felt afterwards, whether they encountered any challenges and how they resolved them. Using a Likert scale (Likert, 1932) with seven statements, volunteers rated their favourite aspect of the project (Table S3). Volunteers were asked to describe any skills or knowledge gained through volunteering for the project, and if their motivations have changed over time. To gauge their interest in learning more about the laboratory process, volunteers were asked if they would like the option to track their samples. Volunteers were asked for feedback on the project's design to enhance future CS experiences, as well as their willingness to volunteer for the research project again. Following the post-sampling survey, a results workshop was organised at Hanningfield Reservoir (Giffords Ln, Downham, Chelmsford CM3 8HX) to share and discuss the eDNA metabarcoding results (Fig. 1E).

Data analysis

Survey analysis

All statistical analyses were performed using R v4.2.0 (R Core Team, 2022). To determine the volunteers' primary motivators for participating in this project, a diverging bar chart was created using *ggplot2* to illustrate Likert scale responses (Wickham et al. 2016). To calculate a science capital score for each volunteer, we followed the methods by Archer et al. (2015). The eight variables (Table S5) were used to create a composite measure of science capital and responses were scored as follows: Strongly disagree = 1, disagree = 2, neither agree nor disagree = 3, agree = 4, and strongly agree = 5. The value for each response was summed to generate a single science capital score, which was divided into three groups: low (0–13), medium (14–27), and high (28–40) science capital. A heatmap was created using *ggplot2*

(Wickham et al. 2016), illustrating the volunteer's science capital scores. Thematic analysis (Braun and Clarke, 2006) was conducted on the open-ended responses in the post-sampling (Questions 2 – 7, 9 and 10, Table S3) using NVivo v 1.6.1 (QSR International, Burlington MA, USA). The coding process encompassed both deductive codes that were identified from the research questions and inductive codes that emerged from the data.

Environmental DNA analysis

After bioinformatic analysis, the dataset was split to isolate the sampling sites where both citizen scientists and researchers collected eDNA samples (sites C1- C15, B2, B4 - B14, Fig. 2A, B), allowing for a direct comparison of results. The read counts in the eDNA water replicates for each sampling location were combined and converted into binary presence-absence data. A bar chart was created using *ggplot2* (Wickham et al. 2016) showing the number of sites at which a species was detected along the two river systems by the volunteers and researchers. To determine if the number of sites sampled by the volunteers and researchers was adequate to represent the overall species diversity along both rivers and to estimate the sampling effort needed to fully determine the species richness (Hsieh, Ma, & Chao, 2016), species accumulation curves were created using the R package *iNext* (Hsieh & Chao, 2020). To illustrate the differences in the average species richness in sample sites between the samples collected by researchers and volunteers, box and jitter plots were created using the *tidyverse* R package (Wickham et al. 2019). A paired t-test was used to determine if there was a significant difference between the number of species detected per site by citizen scientists and researchers.

Results

Citizen scientists' engagement

Ten citizen scientists and two EWT staff were involved in the practical workshop. All volunteers read the information sheet and completed the pre-sampling survey. Of the volunteers, there were three females and seven males. Nine volunteers did not have a physical or mental health condition lasting 12 months or more and one volunteer preferred not to say (Table 1). All volunteers were White/British and have some level of education (Table 1). The age distribution of the volunteers fell into five categories, with most volunteers aged 55-64 (3/10 volunteers) and 65-74 (4/10; Table 1).

Table 1. Volunteer information

Table 1. Participant information

Characteristic		Frequency
Gender	Female	3
	Male	7
Ethnicity	White/British	10
Age	18-24 years	1
	25-34 years	1
	55-64 years	3
	65-74 years	4
	75+ years	1
Level of education	A-levels	4
	Apprenticeship	1
	Certificate of Higher Education (CertHE)	1
	Postgraduate Certificate in Education (PGCE)	1
	Degree with Honours	1
	Master's degree	1
	Doctorate	1

Of the ten volunteers in this study, eight had previously heard of eDNA surveys before the start of this project. Volunteers were interested in seven volunteering roles: Wildlife surveys (10/10), habitat maintenance (6/10), environmental work (5/10), practical work (4/10), GPS mapping (3/10), plant identification (3/10) and working with people (2/10). Three volunteers reported that they gained experience through volunteering with the EWT in their role as an *'EWT river warden volunteer'*.

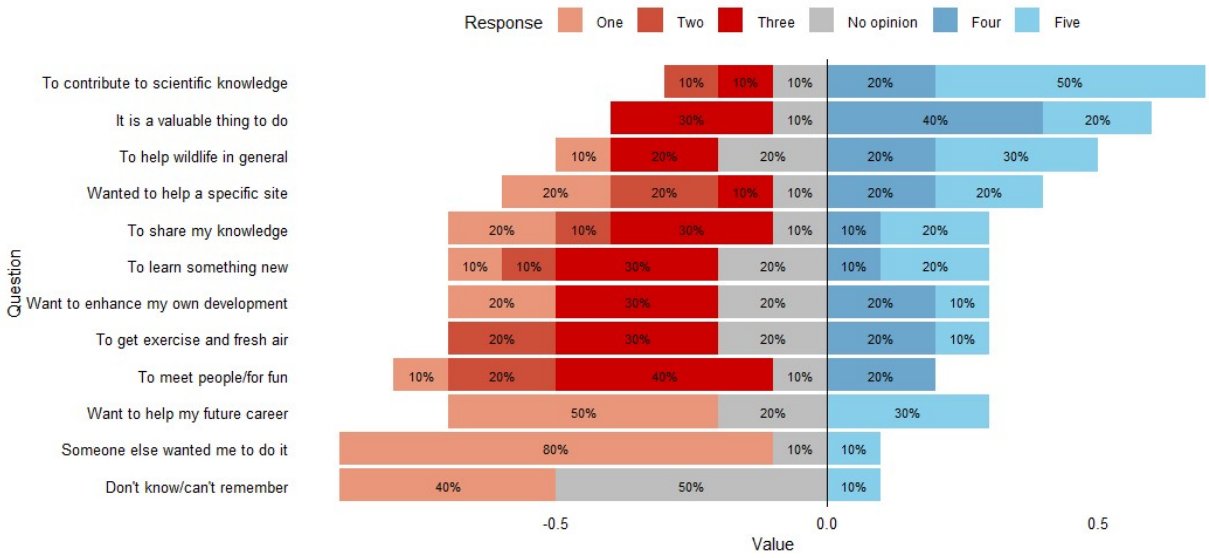

Figure 3. Responses to Likert questions plotted as diverging stacked bar chart presenting the citizen scientists' rating of the different motivational statements.

The science capital question was answered by nine of the ten volunteers and the scores fell between 22 and 39. Four volunteers had a medium score and five volunteers had a high score, with the majority of volunteers scoring 4 or 5 for each variable (Fig. S1). Participants had high levels of 'Science-related attitudes and values' (M = 4.78, SD = 0.416) and 'Consumption of science-related media' (M = 4.44, SD = 0.497), whereas 'Family, science skills, knowledge and qualifications' (M = 2.89, SD = 1.523) and 'Knowing people in a science-related job/role' (M = 2.67, SD = 1.333) were low, respectively (Table S5). The highest-rated motivators can be categorised as intrinsic, including "Help science", "Values", "Help wildlife" and "Specific site concern"

(Fig. 3; Table S4). The two lowest measures of motivation were extrinsic, including "Enhancement" and "Career", and one volunteer was "Responding to a request" (Fig. 3; Table S4).

Post-sampling survey findings

Six volunteers responded to the post-sampling survey. Six key themes were identified in the thematic analysis: "experience and motivation", "emotions and feelings", "learning and acquiring knowledge", "Sense of purpose", "challenges and problem-solving", and "project outcomes and communication" (Fig. 4). The themes and sub-themes are examined here with their corresponding codes and supported by unedited excerpts from the data to highlight significant aspects. The codes are in italics and evidence from survey answers are in italics and quotation marks.

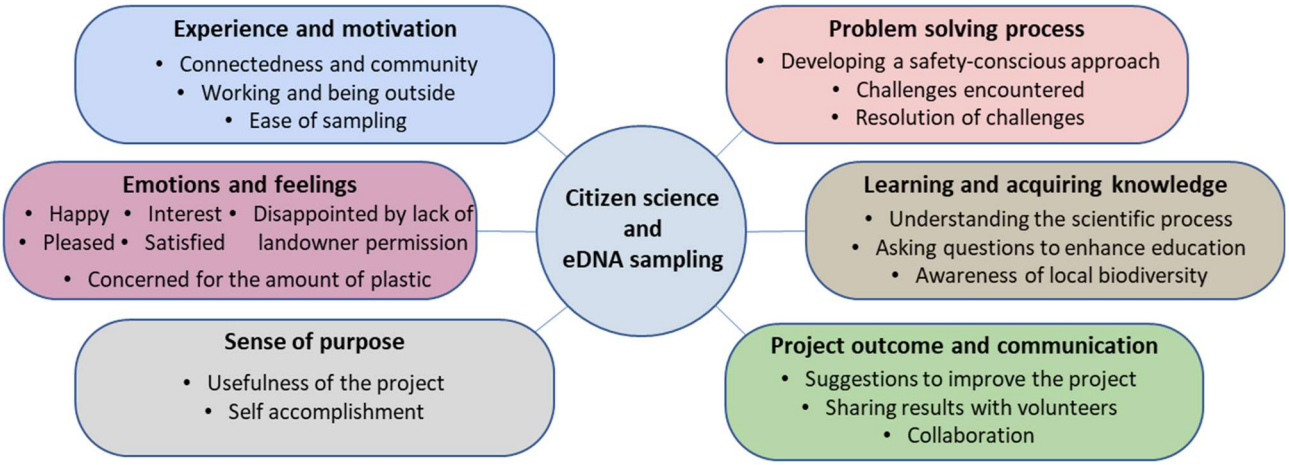

Figure 4. An illustration of the main themes identified through thematic analysis.

Citizen scientists' experience and motivation

Six citizen scientists described the *ease* of collecting and filtering eDNA samples from the rivers, with one volunteer noting that visiting the sampling site was "*fairly straightforward"*. Three volunteers enjoyed *working and being outside* and visiting new

locations. One volunteer enjoyed thinking about and resolving challenges that they encountered during the project. Additionally, one volunteer enjoyed the planning and *organisation* aspect of the work and completed the task relatively quickly. One volunteer did not find anything useful or enjoyable about the filtering stage, despite finding the filtering easy.

Citizen scientists' emotions and feelings

After the eDNA sampling, three volunteers felt *pleased* with the outcome of their work. One volunteer felt "*pleased with the effort and result"* of their work and another felt *pleased* after the filtering stage because it was completed "*without contamination or loss of sample*". Two volunteers reported a sense of *relief* and *satisfaction* upon completing the water filtering. However, *concerns* were raised by three volunteers regarding the environmental impact of the single-use plastic consumables used during the filtering stage and one volunteer was *disappointed* that "*most of the sites - did not receive landowner permission*".

Sense of purpose

Six volunteers reported having a *sense of purpose* through experiencing *self-accomplishment* from their participation, by recognising that their contributions were meaningful and valuable. One volunteer explained that they enjoyed *"being involved in an interesting project, right at the beginning"* and another enjoyed, "*the idea that this would ultimately be of benefit to conservation"*. Six volunteers commented on the *usefulness* of the project, expressing that they are "*glad to be a part of a(*n*) important project"* and that they are "*doing something to help*".

Challenges and problem-solving

Four volunteers reported that the major challenge they faced was collecting eDNA water samples by the river, which required either "*stretching*" or "*bending down*" (Fig. 5A). Three volunteers resolved this challenge by using litter pickers to collect the water sample. The pickers were stored in a plastic bag after use and then sterilised between sample locations using a bleach solution (dilution unknown). Subsequently, they were washed with bottled water to remove residual bleach before the next sample collection (Fig. 5B, C). One comment was:

> *"Using a long reach litter picker for holding the sample bottle, I was able to get away from the river[']s edge, and therefore the sample wasn't e*[a]*ffected by weed and detritus."*

Collecting murky water that may be difficult to filter was also recognised as a challenge, one volunteer "*moved position to be able to collect clearer samples*" and another volunteer used a "*silicon*[e] *gun which worked but was able to squeeze all of the samples by hand".* Additionally, one volunteer was *safety conscious* about collecting water from the rivers and proposed that "*it's best to have at least two people there with one collecting the sample and one as a safety measure*".

Figure 5. Citizen scientists carrying out the environmental DNA (eDNA) sampling: collecting eDNA water samples from the rivers' edge with a water bottle (A) and using

a long-reach litter pick to collect the water sample (B); then sterilizing the litter pick (C).

Learning and acquiring knowledge

All volunteers expressed a strong interest in learning about eDNA metabarcoding which raised advanced questions, one volunteer commented:

> "*The initial lecture was very interesting, but [raised] many more questions like[:] How long does [DNA] stay in the water*[?] *How far does [DNA] drift downstream*[?] *It would be good to see the machinery/process involved in analysing the samples[.] Follow up lecture need[s] to be held to update us on the information*"

Volunteers developed an *understanding* of how the scientific process works, with one volunteer developing an "*appreciation of the possibilities of eDNA*" and another found it "*interesting to see which mammals had been identified"* using eDNA metabarcoding in a previous sampling season. One volunteer expressed uncertainty about learning anything new, and another expected to gain a better understanding of the results with further explanation.

Project Outcomes and Communication

Multiple suggestions were made by the volunteers to improve the project. One volunteer recommended providing larger glove sizes, while another suggested that having images of the sampling site before the start of the project would make it easier to find. The most frequently mentioned suggestion, reported by three volunteers, was to make efforts to reduce the amount of plastic used in the project. One volunteer suggested doing this by either "*reusing sampling bottles/syringes or using non-plastic*

alternatives". After completing the eDNA sampling, four volunteers expressed an interest in learning about the results.

Comparison of wild mammals detected by citizen scientists and researchers

The Illumina MiSeq run yielded a total of 30,369,822 paired-end sequences that passed the quality filtering, across the four libraries and 341 samples (285 eDNA samples and 56 controls). We obtained a relatively equal sequencing depth across all four libraries, representing both researchers' and citizen scientists' eDNA samples (Appendix 1; Table S1). After bioinformatic analysis and subsequent quality filtering, the final dataset contained a total of 4,629,557 reads representing 21 wild mammal species, from five taxonomic orders (Fig 6; Artiodactyla, Carnivora, Eulipotyphla, Rodentia and Lagomorpha) across all sampling locations by both volunteers and researchers. There were 15 species detected along the river Colne (C1 – C15), 18 species detected along the river Blackwater (B4 – B12) and 14 species detected inside and downstream from the beaver enclosure (B1 – B3).

The researchers detected a total of 16 species across all sampling locations: 14 species along the river Colne, 13 species along the river Blackwater and 13 species inside and downstream from the beaver enclosure (Fig. 6). Researchers detected one unique species that the citizen scientists did not, the European mole (*Talpa europaea*) and one unique species inside the beaver enclosure (B1), fallow deer (*Dama dama*). The citizen scientists detected 20 species across all sampling locations, 15 species along the river Colne, 18 species along the river Blackwater and 13 species inside and downstream from the beaver enclosure (Fig. 6). Six species were detected that the researchers did not, including, Yellow-necked mouse (*Apodemus flavicollis*), European brown hare (*Lepus europaeus*), Eurasian pygmy shrew (*Sorex minutus*),

European polecat (*Mustela putorius*) and American mink (*Neovison vison*). Citizen scientists detected one unique species on the river Colne, ten unique species along the river Blackwater, and two unique species downstream from the beaver enclosure (B4).

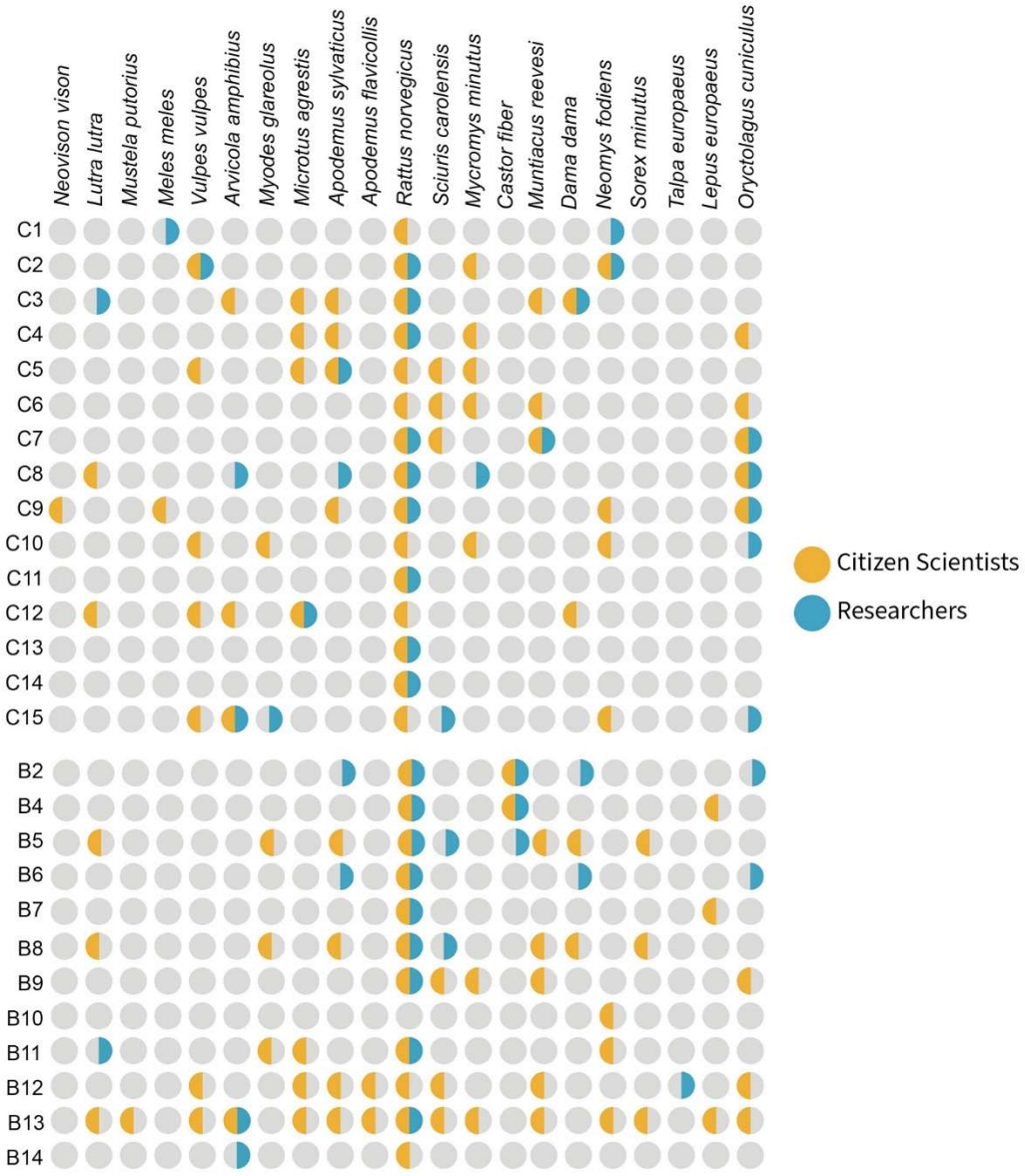

Figure 6. Mammal species detected using eDNA metabarcoding at each eDNA sampling site**.** Sites C6 and C7 were not included here because of discrepancies in the labelled sample bags.

Sampling site effort and species richness

The citizen scientists collected samples had a higher species richness when compared to those collected by the researchers (Fig. 7A). There was a significant difference between the number of species detected per site (paired t-test: P = 0.0007109, df = 26, t-value = 3.5693) and the number of sites a species occurred at (paired t-test: P = 0.00006213, df = 20, t-value = 4.7434) between the citizen scientists and researchers' data (Fig. 6 and S2).

We evaluated the information provided in species accumulation curves to extrapolate how many sample sites are required to capture a comprehensive understanding of the mammalian diversity around the sampling area by both citizen scientists' and researchers' eDNA samples (Fig. 7B). The species accumulation curve for citizen scientist eDNA data had a slight slope increase initially and reached a plateau after a few additional sampling sites. The accumulation curve for researcher eDNA data shows an initial steeper increase and started to plateau at a lower species richness compared with CS eDNA data. These results confirm that more species were detected per sampling effort by the citizen scientists compared to the researcher sampling. Comparisons of extrapolated species accumulation curves for the citizen scientists' eDNA data demonstrated that they could characterise the mammalian community based on fewer samples.

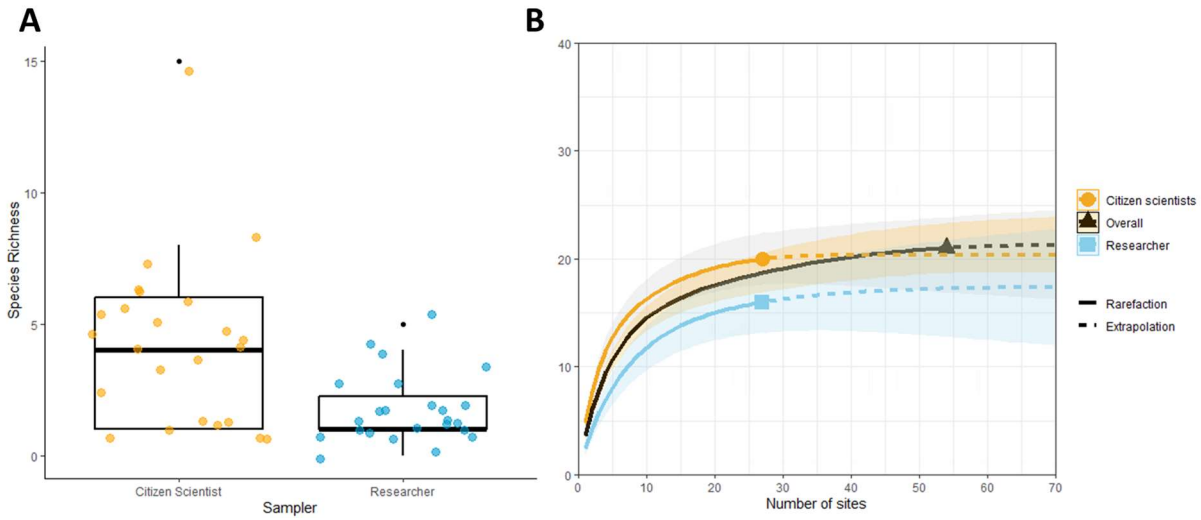

Figure 7. Box plot (A) of the overall species richness for the samples collected along the rivers Colne (C1-C15) and Blackwater (B2, B4-B14) by the citizen scientists and volunteers. Accumulation curve (B) of species detected according to the number of sampled sites along the rivers Colne (C1-C15) and Blackwater (B2, B4-B14).

Discussion

This study has contributed to the advancement of CS eDNA projects in multiple ways. Our findings highlight the importance of effective two-way communication, shared learning, and mutual benefits between citizen scientists and researchers, offering insights into volunteers' motivations, science capital, and experiences in eDNA surveying. Moreover, our study facilitated a direct comparison between citizen scientist and researchers eDNA samples, providing evidence that supports the validation of CS eDNA surveys.

Citizen Scientists' motivation and science capital

Our study revealed that volunteers in this project were driven by both intrinsic and extrinsic motivators, such as their desire to contribute to scientific knowledge, recognition of the value of their involvement, and their commitment to wildlife

conservation (Fig. 3). These motivators align with prior research, highlighting project goals and conservation interests as key factors influencing CS participation (Alender, 2016; Rotman et al. 2012; Geoghegan et al. 2016). Additionally, our findings are consistent with broader motivational studies, revealing that older volunteers from white ethnic groups tend to exhibit motivations centred around values (West et al. 2021). In contrast, younger individuals, and those from lower socio-economic groups and/or from minority ethnic groups are more inclined to have extrinsic motivations, such as a desire to learn something new and enhance their own development or careers (West et al. 2021; Geoghegan et al. 2016). Understanding the motivations of different cultural groups in CS projects is important for creating inclusive, culturally relevant, and meaningful initiatives (Cooper et al. 2021). By aligning the projects with the interests and priorities of diverse communities, researchers can attract a broader range of volunteers, address potential barriers to participation, and foster collaborative and mutually beneficial relationships with local stakeholders. This approach not only enhances the quality and impact of CS research but also contributes to building more equitable and sustainable scientific practices.

To understand the relationship between volunteer participation in CS projects and their science capital, the dimensions were analysed separately (Fig. S1) and together (Table S5; Archer et al. 2015). The individual science capital scores were medium to high, highlighting the importance of seeing the relevance and value of science in everyday life and being exposed to science-related media. Interestingly, having a family member, friend or peer within the community with a science-related job or qualification was not prominent for this group of volunteers (Fig. S1; Kaakinen et al. 2023). Research suggests that CS projects tend to attract individuals with high levels of science capital, which emphasises the need to recognise potential barriers to

participation in CS, such as limited accessibility, resources, language, and technological literacy challenges (Edwards et al., 2018; Cooper et al. 2021; Pateman et al., 2021).

Citizen scientists' experiences

In this study we encouraged an open and transparent two-way communication with volunteers, and we gained insights into the positive aspects and challenges involved in eDNA surveying by inviting them to evaluate project components (Receveur et al. 2022; Robinson et al. 2018), resembling the concept of extended peer review approach (Hacklay et al. 2023). The volunteers had an overall positive experience and remained motivated to participate in eDNA sampling, finding joy in engaging with nature, working outdoors, exploring new locations, and communicating about science (Fig. 4). Additionally, volunteers gained new skills and knowledge which sparked advanced questions about eDNA metabarcoding (Fig. 4). This shows the potential for eDNA CS projects to enhance volunteers' understanding of eDNA and biodiversity as the method becomes more widely used (Suzuki-Ohno et al. 2023).

The volunteers' experiences extended beyond enjoyment of data collection, with genuine expressions of environmental concerns related to the use of plastic waste in eDNA sampling (Fig. 5A, B, C), despite understanding its necessity to prevent cross-contamination between sampling sites. Their concerns emphasise the importance of exploring alternative methods, such as the direct immersion of filters into the water system for eDNA capture (Bessey et al. 2021). Additionally, volunteers encountered challenges during data collection but created innovative sampling solutions, leading to a rewarding experience (Fig. 5A and 6B). Integrating volunteer perspectives and experiences enriched the project and proved to be crucial in our research as we were

able to address the challenges encountered during eDNA sampling. For example, the EWT took proactive measures by contacting landowners in advance to obtain survey permissions for future projects.

Comparison of species detections

Validating CS-collected data is crucial for its usability (Freitag et al. 2016), particularly in the expanding field of eDNA. We ensured that citizen scientists received comprehensive training and support through an interactive seminar and workshop (Pocock et al., 2014; Tweddle et al., 2012). This praxeological approach allowed them to collect high-quality eDNA samples as they detected significantly more mammals overall and between sites compared to researchers (Fig. 6 and S2). As active contributors to the scientific process, the volunteers brought their local knowledge and familiarity with the sampling area to the project, enhancing the data collection process (Danielsen et al. 2018; IPBES, 2019; Receveur et al. 2022). A recent comprehensive assessment on a global level has emphasised that the engagement of Indigenous peoples and local communities in the management and decision-making process stands as the foremost approach for ensuring successful and enduring conservation of biodiversity (Dawson et al. 2021). Moreover, the engagement of local volunteers in data collection saves on significant fieldwork costs (non-local researchers would likely need to hire a vehicle and pay for accommodation during sample collection for example), enabling researchers to allocate resources more efficiently and potentially expand the scope of their research.

Project outcomes

The volunteers expressed an interest in a results workshop stemming from their participation to learn about the project outcomes (Fig. 1E). Sharing the project results with the volunteers and the EWT was an important part of our study, it not only to convey our appreciation and gratitude for their contributions but also served as an educational opportunity and deepened their understanding of conservation efforts and the scientific process. As a result, the volunteers developed a heightened appreciation for eDNA surveys and found the process of species identification fascinating as they discovered the diverse range of mammals they had detected. We consider it highly important for researchers to actively engage in the process of science dissemination, including training and communicating with volunteers (Receveur et al. 2022; Robinson et al. 2018).

Conclusion

The use of eDNA surveys for species monitoring is still a relatively new approach but holds the potential to support conservation efforts and provide valuable learning experiences for everyone involved. As the number of CS eDNA projects continues to grow, there is a parallel increase in the knowledge that can be accumulated from these projects. In this study, we assessed the potential of citizen scientists to collect and filter eDNA water samples for detecting mammalian communities, while focusing on the benefits for both citizen scientists and researchers. Our findings indicated that citizen scientists demonstrated high levels of engagement and motivation for eDNA sampling, but also concern for the environment.

To ensure accessibility and inclusivity for individuals with limited scientific knowledge or experience with science, comprehensive training in eDNA sampling is necessary.

While volunteers can collect eDNA high-quality data with minimal training (Biggs et al. 2015; Agersnap et al. 2022), this approach may primarily reach volunteers who already possess a high science capital, as they are more likely to understand the scientific process (Edwards et al. 2018). Therefore, it is important to create initiatives that are accessible, inclusive, and welcoming to individuals with diverse backgrounds to enable long-term participation, collaboration, knowledge sharing and conducting citizen science-driven eDNA surveys at much larger geographical scales.

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Author contributions

HAB, NGS, RR, EO and ADM conceived and designed the project. HAB, ES, JMJ, DT and NS performed the eDNA sampling. HAB and ES performed the laboratory work, and HAB carried out the bioinformatics and analyses of the eDNA and questionnaire data. HAB wrote the manuscript and all authors read and commented on the manuscript.

Conflict of interest

The authors declare that no conflict of interest exists.

Data availability statement

Raw sequence data will be made available in Dryad and bioinformatic steps and scripts will be made available in Zenodo upon publication.

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