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ASSESSMENT OF HUNGARIAN NATURE CONSERVATION CITIZEN SCIENCE PROJECTS IN A MULTIDIMENSIONAL FRAMEWORK

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CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

CS	Citizen Science
NCCS	Nature Conservation Citizen Science
ECSA	European Association of Citizen Science
ARM	Amphibian and Reptile Mapping
TIR	Hungarian Nature Conservation Information System
GBIF	Global Biodiversity Information Facility
GBF	Global Biodiversity Framework GBF
ALLEA	European Code of Conduct for Research Integrity
HAS	Hungarian Academy of Sciences
MMM	Common Bird Monitoring Program
IBA	Bird and Biodiversity Areas
eBMS	Pan-European Butterfly Monitoring Scheme
SDGs	United Nations Sustainable Development Goals
BMS	Butterfly Monitoring Scheme
SERC	Smithsonian Environmental Research Center
SPI	Science Products Inventory
ATOSS	National Science Foundation’s Attitudes Toward Organized Science Scale
NEP	New Environmental Paradigm

1. INTRODUCTION

Citizen science (CS) has emerged as a transformative force in scientific research and environmental stewardship, fundamentally altering the ways in which new scientific knowledge is generated, shared, and applied to pressing global challenges (Bonney et al., 2014). At its core, CS is defined as the collaborative involvement of non-professional volunteers (citizen scientists) in various aspects of the scientific process, including data collection, analysis, and dissemination of findings (Serrano-Sanz et al., 2014; Bonney et al., 2014; Haklay et al., 2021). While the terminology may vary, with terms such as community science, participatory monitoring, and civic science often used interchangeably, the underlying principle remains the meaningful engagement of the public in scientific inquiry (Eitzel et al., 2017).

The rise of CS is closely linked to technological advancements and the widespread availability of digital tools, which have enabled unprecedented levels of public participation in research. Internet platforms, smartphone applications, and user-friendly data collection interfaces have democratized access to scientific endeavours, allowing volunteers from diverse backgrounds to contribute to large-scale data collection and analysis (Newman et al., 2012; Pocock et al., 2017). This shift has not only expanded the scope and scale of CS but has also fostered public awareness, education, and a deeper connection between individuals and the natural world (Bela et al., 2016; Haklay et al., 2021).

The growing recognition of citizen science's value is particularly evident in the fields of biodiversity and nature conservation, where volunteer involvement has become a cornerstone of modern research and monitoring efforts (Fraisl et al., 2022). By actively engaging the public in tracking species, observing habitats, and documenting environmental changes, Nature Conservation Citizen Science (NCCS) projects generate extensive, long-term databases that are crucial for detecting biodiversity trends, guiding conservation strategies, and informing evidence-based policy decisions (McKinley et al., 2017; Pocock et al., 2018; Moczek et al., 2021). Notable NCCS initiatives such as eBird, iNaturalist, or the Monarch Larva Monitoring project highlight the breadth of NCCS's impact, demonstrating its ability to address diverse research questions and tackle nature conservation challenges (Kountoupes & Oberhauser, 2008; Aristeidou et al., 2021; Sullivan et al., 2014). Many of the most influential and enduring programs, such as the Christmas Bird Count started in 1900, and the Breeding Bird Survey launched in 1966 (both originating in North America), have not only produced scientifically robust data over decades but have also inspired countless scientific publications (Bock & Root, 1981). NCCS projects have deepened our understanding of species distributions, ecological timing, invasive species dynamics, and disease spread, all while empowering communities to play a direct role in conservation. As a result, NCCS has proven essential for expanding scientific knowledge, supporting effective environmental policies, and fostering a broader culture of stewardship in the face of global environmental challenges (Hyder et al., 2015; Bio Innovation Service, 2018; Vohland et al., 2021).

In Europe, NCCS has a rich history rooted in the continent's cultural and scientific traditions (Vohland et al., 2021). Early initiatives focused on public participation in natural history and biodiversity observations, but the rapid development of digital technology has revolutionized the field (Bonney et al., 2014), enabling broader engagement and more robust data collection (Vohland et al., 2021). The European landscape of NCCS is characterized by strong institutional support in Northern and Western Europe, where national strategies and platforms such as "Bürger schaffen Wissen" in Germany and Artportalen in Sweden have fostered a vibrant culture of public involvement in research (Strasser et al., 2018). In contrast, Central and Eastern Europe face challenges related to social capital and civic engagement, though recent initiatives are beginning to bridge this gap and expand participation (Vohland et al., 2021).

The integration of NCCS into international policy frameworks underscores its growing importance in global nature conservation. The Kunming–Montreal Global Biodiversity Framework GBF explicitly encourages the use of community-based monitoring and NCCS for biodiversity tracking, with a substantial proportion of its indicators designed to include data from citizen scientists and local communities (CBD, 2022). Similarly, the United Nations Sustainable Development Goals (SDGs), particularly those related to life below water and life on land, recognize NCCS as a valuable tool for monitoring progress and informing policy (United Nations, 2015). The Aarhus Convention and EU environmental directives further support public participation in environmental governance, emphasizing the rights of citizens to access information, participate in decision-making, and contribute to scientific knowledge (UNECE, 1998; Bio Innovation Service, 2018). The Invasive Alien Species Regulation (EU 1143/2014), for example, explicitly mandates effective public participation. It states that actions to address invasive alien species must facilitate public input (European Parliament and Council of the European Union, 2014). The European Commission has acknowledged that citizen science projects, involving non-professional volunteers in research and environmental action, can have a significant influence on environmental directives and help in achieving policy goals (European Commission. Directorate General for the Environment, et al., 2018)

Despite its many benefits and growing recognition by international bodies, NCCS also faces challenges related to data quality, representativeness (limited in Central and Eastern European countries), and integration into formal nature conservation policy processes (Fritz et al., 2022). However, best practices, evaluation of NCCS projects and robust scientific protocols can help mitigate these issues, ensuring that NCCS continues to empower communities, enhance scientific literacy, and drive positive change in nature conservation, participants' benefits and scientific impact.

Problem statement and justification

Evidence-based conservation actions depend on long-term databases and comprehensive information about species distributions to effectively address the challenges posed by global change and biodiversity loss (Johnson et al., 2024). Yet, traditional ecological monitoring methods are often expensive, time-consuming, and geographically limited in scope (Ahmed et al., 2022). Increasingly, evidence shows that NCCS initiatives help overcome the geographic limitations of traditional research by enabling data collection in regions/areas that are otherwise difficult to study, thus filling important gaps and broadening the reach of ecological monitoring, besides benefits related to participants and new scientific knowledge production (Theobald et al., 2015; Pocock et al., 2018; Dimson et al., 2023).

However, a persistent challenge in NCCS is ensuring the credibility and reliability of data produced by volunteers. The scientific community frequently raises concerns about the quality of citizen-generated data, citing issues such as unstructured sampling, observer bias, inconsistent verification, and incomplete documentation (Balázs et al., 2021; Downs et al., 2021). These factors can undermine trust in NCCS data and limit its acceptance for scientific research and policy-making. To address these challenges and build confidence, rigorous evaluation of NCCS projects is crucial. Such an evaluation not only helps identify strengths and weaknesses in data collection and management but also guides improvements in project design, redefines volunteer experience, and adjusts quality assurance procedures.

Beyond the challenge of data credibility, NCCS has made significant contributions to life sciences and nature conservation in Europe (Hecker et al., 2018). However, there is a notable regional disparity: while NCCS projects are well established and widely recognized in Western Europe, they are only now gaining broader recognition in Central and Eastern Europe, both in research and policy contexts (Bio Innovation Service, 2018; Vohland et al., 2021). In Hungary, for example, several longstanding NCCS initiatives exist, such as the Common Bird Monitoring Program and WildWatcher (Vadonleső Group et al., 2018; Szép & Gibbons, 2000), yet systematic research and comprehensive evaluation of these projects remain scarce.

Although the evaluation of CS projects is highlighted as a core requirement by the European Citizen Science Association (ECSA) (Robinson et al., 2018), most existing evaluation frameworks focus on single dimensions, such as data quality (Kosmala et al., 2016), learning outcomes (Phillips et al., 2018), or conservation impact (Yang et al., 2019), rather than adopting a multidimensional approach. There is a clear need for frameworks that enable the comparison of NCCS projects across multiple dimensions simultaneously (Bonney, 2021; Somerwill & Wehn, 2022).

Moreover, the literature emphasizes the need for innovative evaluation frameworks that move beyond traditional impact assessments. These frameworks should be customized to specific fields, adopt standardized methods, and remain user-friendly (Bonney et al., 2014; Schaefer et al., 2021). Many existing multidimensional frameworks are either not specifically tailored to NCCS projects, thus missing the nature conservation dimension (Kieslinger et al., 2018) or, in the case of NCCS-specific frameworks, focus on different sets of dimensions and components, excluding participants' outcomes (Turbé et al., 2020; Price-Jones et al., 2022). For instance, Kieslinger et al. (2017) proposed supporting questions for evaluation, but these were partly open-ended and did not lead to a standardized scoring system, while Turbé et al. (2019) used surveys and statistical analysis without aiming to develop a practical, user-friendly scoring approach. Consequently, a systematic, NCCS-specific framework assessing three dimensions (science, nature conservation, and participants' development) is still lacking.

This dissertation responds to these gaps by proposing and operationalizing a conceptual, three-dimensional framework centred on science, nature conservation, and participants' development. This framework was empirically tested in Hungary to address the absence of systematic NCCS evaluation in the CCE context. In doing so, it enhances the evidence base for NCCS, supports visibility and recognition of Hungarian projects, and strengthens their integration into evidence-based conservation and policy-making processes. However, it is a general framework for NCCS projects that can be applied in other countries as well.

Research objectives and questions

This study aims to strengthen the evidence base for NCCS projects in Hungary by providing a multidimensional assessment of their contributions to science, nature conservation, and participants' development (including knowledge, changes in attitudes and behaviour).

Objective 1. To develop a conceptual framework and evaluation framework for NCCS projects, structured around three core dimensions (science, nature conservation, and participants' development) that are applicable across multiple countries.

1.1 What are the key components of a three-dimensional conceptual framework for evaluating NCCS projects?

1.2 How can these components be translated/operationalized into a practical, user-friendly three-dimensional evaluation framework for NCCS projects' performance assessment?

Objective 2. To assess the scientific contribution of selected Hungarian NCCS projects.

2.1 How do NCCS projects ensure data quality?

2.2 Are the outcomes of NCCS projects scientifically robust?

Objective 3. To assess the nature conservation role of selected Hungarian NCCS projects.

3.1 How can NCCS projects contribute directly to the monitoring of species?

3.2 How are NCCS project outcomes utilized in species management?

3.3 How are NCCS project outcomes utilized in policies and conservation actions?

Objective 4. To assess the impact of selected NCCS projects on participants' development.

4.1 What motivates citizens to get involved in the selected NCCS projects?

4.2 How do NCCS projects influence the knowledge of participants?

4.3 How do NCCS projects influence participants' attitudes and behaviours?

2. LITERATURE REVIEW

2.1. Citizen Science: Definitions and evolution

Definition

Citizen science (CS) is a collaborative approach to scientific research that involves the active participation of non-professional volunteers, or "citizen scientists," in various aspects of the scientific process, including data collection, analysis, and dissemination of findings (Bonney et al., 2014; Serrano-Sanz et al., 2014). This practice not only enhances scientific knowledge but also fosters public engagement and environmental awareness (Bela et al., 2016). Despite ongoing discussions about the terminology and scope of citizen science, its core principles remain focused on public involvement in scientific inquiry (Haklay et al., 2021). Table 1 shows various definitions of CS.

Table 1. Selection of citizen science definitions from various scientific literature sources and relevant institutions in the citizen science field

Literature Reference	**Definitions**
Oxford English Dictionary (2014)	"Scientific work is undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions."
European Citizen Science Association (ECSA)	"The participation of the general public in scientific processes. Citizen science projects actively involve citizens in scientific endeavours that generate new knowledge or understanding."
(Serrano-Sanz et al., 2014)	"Citizen Science refers to the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources."
Bonney et al. (2014)	"Citizen science is a form of public participation in scientific research, where volunteers contribute to scientific projects by collecting data, analysing results, and sharing findings, thereby enhancing scientific knowledge and engagement."
Silvertown (2009)	"Citizen science is an approach that involves the public in scientific research related to scientists' interests."
(Haklay, 2013)	"Citizen science involves the participation of volunteers in scientific research. While volunteers typically focus on data collection, they may also play roles in formulating research questions, designing projects, sharing findings, and analysing data."

History of Citizen Science

The term "scientist" was introduced in 1833 and gradually gained traction, reflecting a relatively recent Eurocentric view of science as a profession that developed from the 17th to 19th centuries. Researchers, initially known as "natural philosophers," often had other jobs or were financially supported by patrons. Knowledge was primarily trusted when presented by "gentlemen," while technicians working in their laboratories were often overlooked and deemed "invisible."(Eitzel et al., 2017).

Citizen science, defined by Bonney (1996) as participatory data collection, has a long history, even before the term was widely used. Historically, most scientific research was carried out by amateurs rather than paid professionals (Miller-Rushing et al., 2012). A significant example is Charles Darwin, who, despite his medical training and significant contributions to the theory of evolution, was an unpaid companion on the HMS Beagle ship around the world (Eitzel et al., 2017).

The origins of citizen science are a subject of considerable debate. Historical records indicate that in 8th century, individuals in Kyoto, Japan, were engaged in documenting the blooming of Sakura (cherry blossoms) (Aono & Kazui, 2008). However, the formal concept of citizen science is often linked to the late 19th century in the United States, where amateur observers participated in Audubon Christmas Bird Count, which is recognized as the first and oldest citizen science project (Bock & Root, 1981).

Citizen Scientists

Citizen scientists are individuals who voluntarily contribute to scientific research, often without formal previous expertise in the scientific field. They engage in various activities, such as data collection, observation, and analysis, to assist professional scientists in advancing knowledge across diverse disciplines, including ecology, astronomy, and public health. Citizen scientists play a crucial role in expanding the scope of research by providing large amounts of data that might otherwise be difficult to obtain (Miller-Rushing et al., 2012; Agnello et al., 2022).

Principles of Citizen Science

The European Citizen Science Association (ECSA) has established ten guiding principles for the effective implementation of citizen science projects promoting good practices (Robinson et al., 2018). These principles emphasize the importance of engaging citizens in scientific research, ensuring that their contributions are significant and appropriately recognized. Collaboration between professional scientists and citizen scientists is essential, as it fosters a shared creation of knowledge that enhances research quality while promoting public involvement and understanding of scientific methods. The statements in Figure 1, were developed by the ‘Sharing best practice and building capacity’ working group of ECSA, led by the Natural History Museum, London, with input from many members of ECSA.

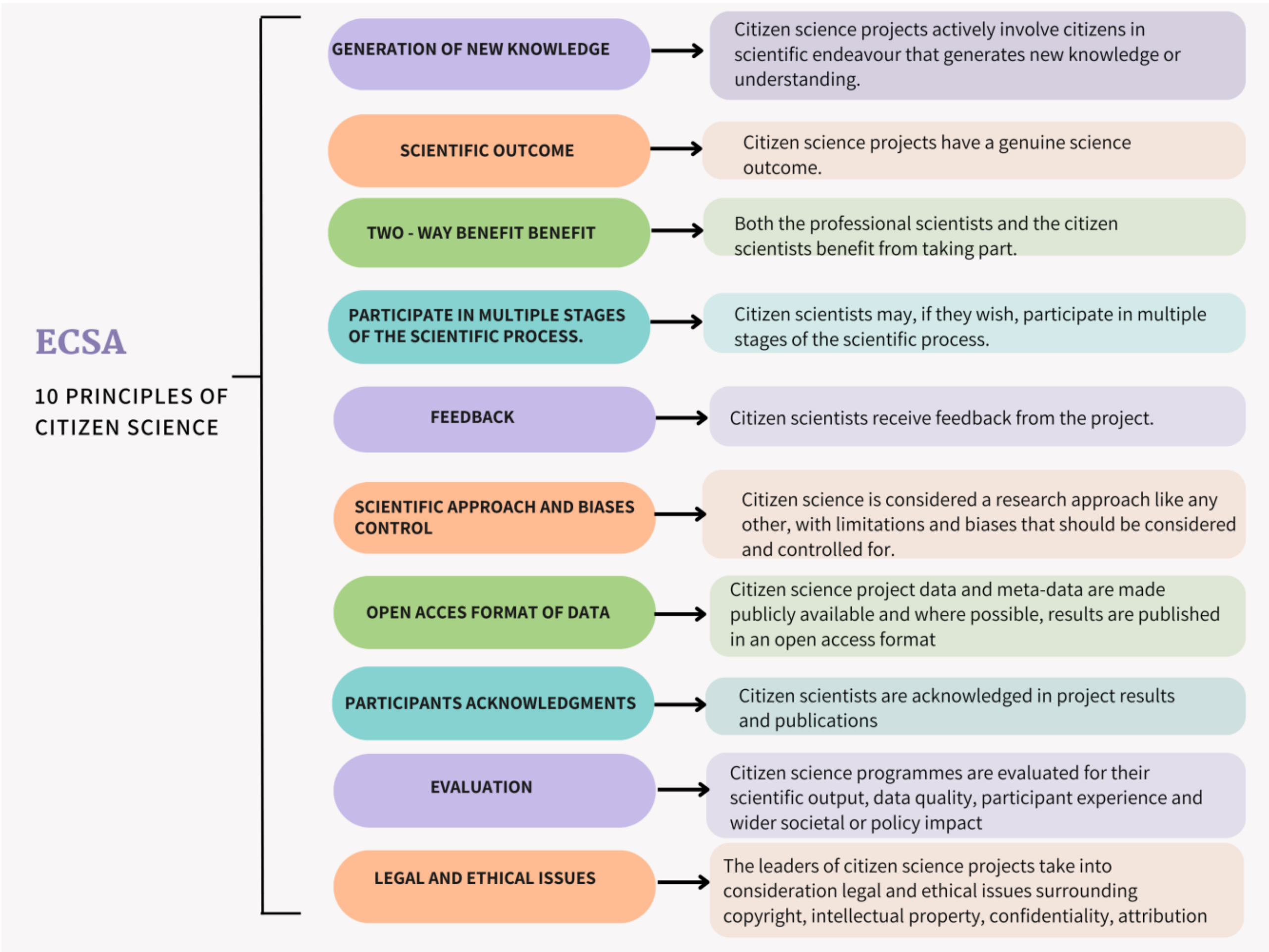

Figure 1. The ten principles of citizen science of ECSA (own compilation based on Robinson et al., 2018)

Additionally, ECSA's principles highlight the necessity of transparency, ethical considerations, and inclusivity within citizen science initiatives. Projects should be designed to be accessible to a diverse range of participants, encouraging engagement from various communities. By prioritizing these values, citizen science can empower individuals, improve scientific literacy, and address both local and global challenges through collective action. Ultimately, the ECSA principles aim to elevate the standards of citizen science, ensuring it effectively contributes to scientific knowledge and societal advancement.

Typologies of Citizen Science

Citizen science can be categorized into three primary types based on the level of involvement and collaboration between citizen scientists and professional researchers: contributory, collaborative, and co-created citizen science (Bonney et al., 2009) (see Table 2).

a) Contributory Citizen Science: In contributory citizen science projects, participants primarily collect data or observations that are then utilized by professional scientists for research purposes. The role of citizen scientists is often limited to data collection, following specific protocols and guidelines set by researchers. This model allows for large-scale data gathering, which can be particularly useful in fields such as ecology, astronomy, and environmental monitoring. For example, the eBird project (managed by the Cornell Lab of Ornithology), allows birdwatchers to report their observations of bird species from around the world. Participants submit data on bird sightings, which is then used by researchers to study bird distribution, migration, and population trends (Sullivan et al., 2014).

b) Collaborative Citizen Science: Collaborative citizen science involves a more integrated approach, where citizen scientists work alongside professional researchers throughout the research process. Participants may assist in various stages, including study design, data collection, analysis, and dissemination of findings. This model fosters a deeper engagement and understanding of the scientific process among participants. For example, the Monarch Larva Monitoring Project (MLMP), where participants work closely with researchers to design monitoring protocols, share findings, and contribute to data analysis. Through this partnership, both scientists and citizen scientists learn from each other, enhancing the understanding of monarch populations (Kountoupes & Oberhauser, 2008).

c) Co-created Citizen Science: In co-created CS projects, citizens and scientists collaborate equally in all aspects of the research process. This approach emphasizes shared decision-making, mutual learning, and co-design of the research questions and methodologies. One example is the CitieS-Health project, where participants raise questions and share their knowledge about environmental epidemiology with an emphasis on community health. They are involved in every step of the research process, ensuring that their insights and concerns are integrated into the study (Froeling et al., 2024).

These three types of citizen science highlight the varying degrees of participation and collaboration, each contributing uniquely to scientific research and public engagement.

Table 2. Simplified classification of citizen science projects (Bonney et al., 2009).

Types of citizen science	Level of engagement of participants
Contributory	Participants contribute data or observations, often with minimal involvement in the research process.
Collaborative	Participants work together with researchers, contributing data and insights, but the researchers retain control over the project.
Co-created Citizen Science	Participants co-design, execute, and analyse the data of the project, sharing responsibilities with researchers.

2.2. Citizen Science in Europe

CS in Europe has a rich history that reflects the continent's diverse cultural and scientific landscapes. Originating in the Renaissance era, early CS initiatives on the continent primarily involved public participation in natural history and biodiversity observations (Miller-Rushing et al., 2012; Vohland et al., 2021). Over the years, the rapid development of digital technology and wide internet access have revolutionized these efforts, enabling broader engagement through online platforms and mobile applications (Vayena & Tasioulas, 2015). Today, the European landscape of CS projects spans various fields, including environmental monitoring, health research, and social sciences, showcasing the potential of the field in generating valuable data and insights for science, policy and decision making (Hecker et al., 2018). The evolution of citizen science has been marked by varying levels of institutional support and public awareness, which differ significantly across regions (Vohland et al., 2021).

Citizen Science in Northern and Western Europe

Citizen science in Northern and Western Europe has a long tradition, exemplified by national bird monitoring such as the Breeding Bird Survey (BBS) from the mid-1990s and decades-long marine observation efforts across the North Sea that sustain continuous bird and marine mammal records (Garcia-Soto et al., 2021; Massimino et al., 2025). NCCS in these regions has experienced significant growth and institutional support, fostering a diverse and vibrant landscape of projects across multiple fields (natural sciences, astronomy, health) (Hecker et al., 2018; Turbé et al., 2020). Popularity accelerated in the early 2010s as enabling factors converged: EU policy embedded citizen science within Open Science and Responsible Research and Innovation (notably Horizon 2020’s SwafS), providing legitimacy, funding that encouraged institutional uptake (Strasser et al., 2018). CS in the regions is characterized by strong university and museum leadership, and mature partnerships with environmental agencies, NGOs, and research infrastructures (Vohland et al., 2021). The dominant field is biodiversity and environmental monitoring (e.g., birds, phenology, invasive species), complemented by established niches in astronomy (large-scale classification projects) and an expanding health/biomedicine segment engaging patients and communities (Turbé et al., 2020). Countries in these regions have benefited from strong research in CS and public engagement, enabling citizens to contribute meaningfully to environmental monitoring, biodiversity conservation, and health research (Hecker et al., 2018; Turbé et al., 2020; Vohland et al., 2021).

Various national strategies and initiatives in the region, such as "Bürger schaffen Wissen" (Citizens Create Knowledge) in Germany, the Artportalen platform in Sweden, and the national citizen science platform "Österreich forscht" in Austria, have been instrumental in promoting public involvement in research (Schleicher & Schmidt, 2020). These initiatives have created a supportive environment that encourages active participation from citizens, resulting in numerous successful CS projects that draw on extensive experience and expertise. This collaborative approach not only enhances scientific research but also fosters a culture of engagement and empowerment among the public (Vohland et al., 2021).

Citizen Science in Central and Eastern (CCE) Europe

The development of CS projects in Central and Eastern Europe faces several challenges (Turbé et al., 2020). The region's history of socio-political transitions has led to a low level of social capital and a relatively brief tradition of civic engagement, which can make it difficult for CS initiatives to flourish (Kozlowski et al., 1999). Furthermore, the perceived low number of citizen science projects in this region may reflect uneven patterns of knowledge production, where language divides limit both participation and the visibility (dissemination of results, citation, availability in international repositories) of project outputs produced in non-English contexts (Vohland et al., 2021). In spite of the fact that historically, opportunities for public involvement in scientific research remain largely untapped in CCE countries (Bio Innovation Service, 2018; Suškevičs et al., 2021), initiatives are starting to bridge this gap (Bela et al., 2016; Vadonleső Group et al., 2018; Duží et al., 2019; Konowalik et al., 2020).

Citizen science is emerging in the Czech Republic with projects (e.g. Action Frog, InterDrought), showing a growing academic-NGO collaboration and a need for further study according to Duží et al. (2019). In Poland, citizen science projects (e.g., Design Poland of your dreams, Breeding Bird Atlas of Poland - Atlas ptaków lęgowych, OTOP BirdLife Poland) have already begun to inform the Polish government's strategic objectives. These projects contribute valuable data and insights that align with national priorities, particularly in areas such as environmental monitoring and biodiversity conservation (Gawrońska-Nowak et al., 2023).

2.3. Nature Conservation-related Citizen Science (NCCS)

Citizen science in nature conservation involves the active engagement of non-professional volunteers in scientific research and monitoring activities that contribute to biodiversity protection, ecosystem management, and the development of environmental policies. By enabling public participation, citizen science expands the reach and impact of conservation efforts, allowing for broader data collection and fostering a deeper connection between people and the natural world (McKinley et al., 2017).

NCCS is a specific subset of citizen science initiatives focused on generating knowledge and supporting action for biodiversity and ecosystem protection. While general citizen science projects can span a wide range of scientific fields, NCCS projects typically engage citizens in a variety of conservation-related activities, including:

- Observing and recording species in their local environment (White et al., 2023).
- Collecting ecological and environmental data (Moczek et al., 2021).
- Monitoring habitats and ecological changes (Niedertscheider et al., 2012; Fraisl et al., 2022; Kasten et al., 2021).
- Collecting data for species or ecosystems management (Chandler et al., 2017; Lee et al., 2021).
- Contributing to decision-making processes in conservation (Bio Innovation Service, 2018).
- Benefits for participants, as called by Bela et al. (2016) the transformative potential of CS, raising conservation awareness, and encouraging pro-environmental attitudes and behaviours.

By engaging in these activities, volunteers play a key role in monitoring biodiversity, protecting habitats, identifying human-wildlife conflicts, and managing invasive species. In some cases, their efforts have a direct impact on conservation measures at both local and national scales. The ecological data generated by NCCS projects are invaluable for addressing knowledge gaps and guiding evidence-based management and policy decisions across all levels (McKinley et al., 2017; Criscuolo et al., 2023). Notably, major global biodiversity platforms such as the Global Biodiversity Information Facility (GBIF) now source at least half of their species occurrence records from NCCS efforts, highlighting the significant contribution these projects make to international conservation science (Miller, 2022).

Several successful NCCS projects have demonstrated how public participation can directly contribute to nature conservation. For instance, eBird is a global NCCS project managed by the Cornell Lab of Ornithology, engaging millions of volunteers with no previous experience needed worldwide to contribute bird observation data. This extensive international participation has transformed eBird into one of the largest NCCS projects in existence. The project plays a critical role in supporting the implementation of the EU Birds Directive and aids significantly in identifying Important Bird and Biodiversity Areas (IBAs) across Europe. By aggregating vast amounts of real-time observation data, eBird provides essential information for large-scale bird population monitoring, species trend analysis, and conservation priority-setting. Importantly, the data generated through eBird are regularly utilized by policymakers, researchers, and conservation organizations to inform management actions and assess the conservation status of protected bird species, ensuring that evidence-based strategies guide bird conservation efforts both within Europe and globally (Sullivan et al., 2009).

The Pan-European Butterfly Monitoring Scheme (eBMS) is a collaborative network that standardizes and coordinates butterfly monitoring across more than 20 European countries, integrating both expert and volunteer observations (UK Centre for Ecology & Hydrology, UKCEH, 2025). By employing standard field protocols, eBMS has produced some of the largest datasets on butterfly populations in Europe, enabling high-quality, comparable trend analyses across national boundaries. The data generated are crucial for assessing changes in butterfly abundance and distribution, and they serve as a core biodiversity indicator for European Union policy, including the EU Pollinators Initiative and biodiversity strategy directives. eBMS results have guided national Red List status reviews, helped prioritize protected areas under the Natura 2000 network, and informed agro-environmental measures such as those within the Common Agricultural Policy. Beyond its direct influence on conservation policy and land management, eBMS also fosters public engagement with nature, involving thousands of citizens in scientific monitoring each year and raising awareness about pollinator declines and habitat conservation across the continent (Dennis et al., 2017).

Hungary has been actively contributing to butterfly conservation through its national BMS, established in 2016 and aligned with the eBMS. Coordinated by the Hungarian Lepidopterists Society, the scheme engages trained volunteers to monitor butterfly populations using standardized methods. Supported by EU projects like ABLE, Hungary now maintains 20–30 active transects, with data feeding into national databases such as OpenBioMaps (Bán et al., 2022) and international platforms like eBMS. This citizen science initiative plays a key role in tracking over 130 butterfly species, informing EU-level conservation policies including the Habitats Directive and the EU Pollinators Initiative, while also fostering public engagement in biodiversity monitoring (Dennis et al., 2017; Süle et al., 2023).

2.4. International policy initiatives and NCCS

Kunming–Montreal Global Biodiversity Framework (GBF)

The Kunming–Montreal Global Biodiversity Framework (GBF), adopted under the Convention on Biological Diversity (CBD) in 2022, marks a significant milestone in global conservation policy by explicitly encouraging the integration of community-based monitoring and citizen science into biodiversity tracking efforts. This framework recognizes the vital role of citizen science in achieving biodiversity targets, with a substantial number of its 365 monitoring indicators designed to include data contributions from citizen scientists and local communities. By formally acknowledging citizen science, the GBF empowers countries and organizations to leverage public participation for more comprehensive and effective biodiversity monitoring and conservation outcomes (Convention on Biological Diversity - CBD, 2022) (Table 3).

United Nations Sustainable Development Goals (SDGs)

Citizen science is increasingly recognized as a valuable tool for supporting the United Nations Sustainable Development Goals (SDGs), particularly those related to environmental sustainability such as SDG 14 (Life Below Water) and SDG 15 (Life on Land). Through widespread public engagement in data collection and monitoring, citizen science projects contribute essential information for SDG reporting and help inform environmental policy at both national and international levels. International inventories and studies commissioned by the European Commission have highlighted the practical impact of citizen science in tracking progress toward these global goals, demonstrating its growing importance in sustainable development efforts (United Nations, 2015) (Table 3).

Aarhus Convention

The Aarhus Convention, established by the United Nations Economic Commission for Europe (UNECE) in 1998, provides a legal foundation for public rights regarding access to environmental information, participation in decision-making, and access to justice in environmental matters. Legal experts and practitioners have proposed expanding the convention's framework to include a civic “right to contribute environmental information,” which would further legitimize and support the role of citizen science in environmental governance. This development would affirm the value of citizen-generated data and promote greater public involvement in environmental decision-making processes at the international level (United Nations Economic Commission for Europe (UNECE), 1998) (Table 3).

EU Nature Conservation Directives and Policy Initiatives

The European Union has increasingly recognized the potential of citizen science for environmental policy, integrating it into the monitoring and implementation of key directives such as the Birds Directive (Directive 2009/147/EC, 2009), Habitats Directive (Council Directive 92/43/EEC, 1992), and Water Framework Directive (Directive 2000/60/EC, 2000). The European Commission has commissioned studies and policy papers that recommend removing barriers to citizen science participation and developing common data infrastructures to facilitate its use in EU-wide environmental monitoring and compliance. Projects with robust scientific protocols and strong partnerships with governmental agencies are more likely to influence policy and management decisions, highlighting the importance of accessible participation and scientific rigor in maximizing the impact of citizen science on conservation policy (Bio Innovation Service, 2018) (Table 3).

Table 3. International law or policies related to NCCS

Instrument/Policy	**Relevance to NCCS**
Kunming–Montreal Global Biodiversity Framework (GBF)-(CBD)	Explicitly encourages citizen science for biodiversity monitoring
Aarhus Convention	Provides a legal basis for public participation and information
UN SDGs	Citizen science supports data collection and progress tracking
EU Environmental Directives	Increasingly integrating citizen science for monitoring and reporting

2.5. Assessment frameworks for NCCS projects

Evaluation of CS projects is recognized as a fundamental aspect of good practice (Heigl et al., 2020), explicitly emphasized in Principle 9 of the European Citizen Science Association (ECSA) Ten Principles (Robinson et al., 2018). This principle suggests the systematic assessment of CS project outcomes, data quality, and participant engagement as a core requirement for all CS initiatives. Importantly, it emphasizes that evaluation should be integrated throughout the entire project lifecycle, not just at the conclusion (Robinson et al., 2018). Despite this, many CS projects still lack consistent and thorough evaluation, leaving uncertainties about their true effectiveness and impact on conservation outcomes (Kieslinger et al., 2018).

A variety of assessment frameworks have emerged to address these challenges, moving beyond simple metrics like data quantity (Kosmala et al., 2016) and increasingly ecological impact (Tredick et al., 2017), social, and learning outcomes (Phillips et al., 2018). These frameworks often categorize evaluation criteria into separate dimensions.

However, only a limited number of frameworks take a truly multidimensional approach to evaluating CS projects. The framework developed by Kieslinger et al. (2018) evaluates diverse CS projects, including those focused on nature conservation. The evaluation covers three key dimensions: the scientific dimension (assesses data quality and research outputs), the social dimension (explores participant engagement and learning outcomes) and the socio-ecological and economic dimension (examines the conservation impact and policy relevance of the projects). The authors' framework provides indicators at both process and outcome levels, supporting internal evaluation and external funding reviews.

Turbé et al. (2020) target European NCCS projects with policy relevance by evaluating contributions to policy, data management, and participant involvement, thus enabling comparison across multiple criteria. Similarly, Price-Jones et al. (2022) evaluate 103 NCCS projects specifically targeting invasive species in Europe, considering variables such as data quality, data management, and participant engagement.

Despite these advances, there remains a pressing need for frameworks that enable comprehensive, multidimensional comparison of exclusively NCCS projects in more dimensions (Bonney, 2021; Somerwill & Wehn, 2022). The lack of comprehensive, multidimensional frameworks for NCCS projects makes it challenging to standardize evaluation criteria across different initiatives (Heigl et al., 2019; Arbour, 2020). As a result, comparing project outcomes and identifying effective approaches becomes difficult, which in turn hinders the sharing of knowledge and best practices within the field. This fragmentation also reduces transparency, as stakeholders may find it hard to interpret and assess the true impact of various projects without consistent evaluation methods. Furthermore, the absence of standardized frameworks limits the ability to build a robust evidence base, making it more difficult to aggregate NCCS outcomes into the acceptance of the scientific community or funders. Overall, the adoption of multidimensional evaluation frameworks is essential for enabling meaningful comparisons, fostering continuous improvement, and clearly demonstrating the value and impact of NCCS projects (Bonney, 2021; Somerwill & Wehn, 2022).

2.6. Science dimension of NCCS

NCCS projects have emerged as powerful tools for collecting large-scale ecological data, engaging the public in scientific inquiry, and supporting science-based research to answer scientific questions (McKinley et al., 2017; Fraisl et al., 2022). These initiatives are instrumental in producing large-scale, high-quality databases (when ensuring high standards of data quality) that underpin ecological research, inform management decisions, and shape conservation policies (Cunha et al., 2017; Callaghan, et al., 2021). However, the scientific value and credibility of NCCS projects hinge on the rigorous application of scientific standards (Finger et al., 2023; Flowers et al., 2023) throughout all stages of the research process, from data collection to analysis and dissemination, depending of the level of engagement of the project (Bonney et al., 2009).

Ensuring scientific rigor in NCCS projects remains a central concern, particularly given the variability in participant expertise and the risk of data inaccuracies, such as species misidentification by non-experts (Freitag et al., 2016; Balázs et al., 2021; Callaghan, et al., 2021). Such errors can introduce significant biases, ultimately undermining the reliability of the data and the trust of the scientific community, policymakers, and the public (Horton et al., 2016; Farr et al., 2023). To address these challenges, NCCS projects have increasingly adopted a multi-strategy approach that integrates several complementary methods to enhance data quality and scientific outcomes (Freitag et al., 2016).

Key strategies for ensuring scientific rigor

Training:

The most frequently employed strategy, according to the literature, to ensure scientific rigor involves providing volunteers with thorough training (Ratnieks et al., 2016), including clear instructions, species identification guides (Márton et al., 2023), and digital resources such as mobile applications and instructional videos (Rittenschober et al., 2021; Hognogi et al., 2023). Studies have shown that when volunteers receive adequate training, the quality of their data can approach that of professional scientists, especially when the training is reinforced and repeated over time. However, the complexity of the tasks (such as identifying challenging species) may require more intensive training, which is not always feasible for all projects (Benyei et al., 2023).

Data quality assurance and expert validation

Data quality assurance is critical for ensuring the reliability of NCCS data. This typically involves expert review and validation of volunteer-submitted records, including systematic checks for completeness, accuracy, and consistency (Castagneyrol et al., 2019; Lindermann et al., 2024). Experts may use statistical analyses, direct communication with volunteers, and established scientific methods to verify and curate data, thus reducing biases and enhancing transparency (Balázs et al., 2021; Barahona-Segovia et al., 2021). The validation process is essential for maintaining the integrity of databases and supporting their use in scientific research and policy-making (Kosmala et al., 2016; Chandler et al., 2017).

Standardized data collection protocols

Implementing standardized protocols ensures that all participants follow consistent procedures for data collection, recording, and reporting (Wiggins et al., 2011). Detailed instructions and clear criteria for observations help minimize variability and errors, making the resulting data more comparable across different locations and time periods (Stenhouse et al., 2020). Projects that rigorously enforce standardization (such as eBird and iNaturalist) have demonstrated significant improvements in data quality and scientific acceptance, serving as models for best practices in citizen science (Kelling, 2018; Ackland et al., 2024).

Technological integration

The adoption of digital tools, including mobile apps, online platforms, and automated identification systems, has greatly enhanced the scientific robustness of NCCS projects (Aide et al., 2013). These technologies provide user-friendly interfaces, guide volunteers through standardized protocols, and incorporate automated features such as GPS tagging and algorithm-based species recognition (Aide et al., 2013; Szép & Gibbons, 2000; McCarthy et al., 2021). Real-time feedback and correction mechanisms, often built into these platforms, further reduce the likelihood of errors and improve overall data quality. In some cases, advanced tools like drones are used for high-resolution ecological surveys, with volunteers and experts collaborating on data analysis (Kobori et al., 2016; Buckland & Johnston, 2017; Samiappan et al., 2024).

Scientific outcomes and impact

The primary scientific outcomes of NCCS projects, when scientific rigor is ensured, are the generation of robust databases and the direct application of these data to management and policy decisions (Haklay et al., 2018; Chapman & Hodges, 2020). Studies have reported successful data outcomes, with high-quality databases being used for biodiversity monitoring, ecological research, and informing conservation actions (Hyder et al., 2015; Bio Innovation Service, 2018; Criscuolo et al., 2023). However, there is a notable gap in the formal dissemination of scientific results, such as peer-reviewed publications and broader science communication (Follett & Strezov, 2015; Jönsson et al., 2024). Strengthening the reporting and communication of findings is essential for maximizing the scientific impact of NCCS and ensuring that valuable insights are recognized and utilized by the broader research community.

The importance of a multi-strategy approach

The literature emphasizes that no single strategy is sufficient to guarantee scientific rigor in NCCS projects. Instead, the simultaneous application of multiple strategies (Soria & Tormáné Kovács, 2025), combining training, validation, standardization, and technology, is crucial for overcoming challenges related to data quality and for maximizing scientific credibility and impact. This multi-strategy approach not only enhances the robustness of scientific outcomes but also increases the acceptance of NCCS projects within the scientific community and among other stakeholders.

Empirical studies measuring the scientific impact of NCCS projects

Farr et al. (2023) evaluated a large-scale NCCS bird monitoring project along Utah’s Jordan River. They provide compelling evidence for the scientific value of citizen-driven data collection. Over three years, both citizen scientists and professional biologists conducted parallel point count bird surveys at identical sites, allowing for a direct comparison of their results. By analysing metrics such as species detection rates and total bird counts, researchers found that (with training and adherence to standardized protocols) data generated by citizen scientists matched the accuracy and reliability of professional observations. These outcomes highlight not only the potential for high-quality scientific data from well-designed citizen science initiatives but also the importance of rigorous training and methodological oversight in achieving reliable results. This empirical evidence supports the view that citizen participation, when thoughtfully integrated, can make substantial scientific contributions to ecological research and conservation efforts.

Wiggins et al. (2018) proposed the Science Products Inventory (SPI) as an innovative framework for the evaluation of scientific outcomes in CS projects. It was created with the objective of enhancing both the rigor and impact of citizen science efforts dedicated to nature conservation and making scientific achievements more visible and fostering a culture of continuous improvement of evaluating scientific outcomes. Through its application in several case studies (including Aurorasaurus, GLOBE Observer, and a range of Smithsonian Environmental Research Center (SERC) CS projects) the SPI enables a systematic assessment of diverse scientific outputs, including datasets, research publications, protocols, digital resources, and educational or outreach materials. The evaluation process employed both quantitative inventories and qualitative staff interviews. The findings highlight that the flexibility and structure of the SPI support not only internal project reflection, strategic planning, and resource allocation but also facilitate organizational learning and benchmarking across projects.

The study by Roman et al. (2017) provides an empirical assessment of data quality in citizen science urban tree inventories. The researchers compared street tree data collected by expert arborists to data collected by citizen science field crews (volunteers with varying levels of experience) in four cities: Lombard, Grand Rapids, Philadelphia, and Malmö. The evaluation focused on observation error across key variables such as tree counts, genus and species identification, site type, land use, diameter at breast height, and tree condition.

Participants showed high consistency with experts for several attributes: about 90% for site type, land use, dieback, and genus identification. Volunteers showed effective species identification, 84.8% of trees. Mortality status was also reported with very high accuracy (99.8% of live trees). However, variables such as crown transparency and wood condition had lower accuracy and were flagged by participants as more difficult to assess, leading the authors to recommend omitting these from future projects. In measuring diameter at breast height, citizen scientists matched expert values exactly for about one-fifth of single-stem trees, but were within 2.54cm for over 93% of cases. A slight systematic bias was observed, with volunteers tending to record larger diameter at breast height values than experts. Issues also arose with multi-stemmed trees, which proved more challenging for consistent measurement.

The main findings demonstrate that volunteer-collected tree inventory data can be sufficiently accurate for many urban forest management and research applications, particularly for genus identification and diameter at breast height at a coarse level of precision. The authors recommend several improvements (including simplified protocols for complex variables, enhanced training materials, especially for species identification), and robust data validation and quality assurance procedures, to further enhance data quality in citizen science-driven urban environmental monitoring. This study provides strong evidence that, with appropriate methods and oversight, citizen scientists can contribute high-quality data to urban forestry initiatives

In summary, the science dimension of NCCS projects is defined by their ability to produce credible, high-quality data through the integration of diverse strategies aimed at ensuring scientific rigor. By adopting a holistic approach that addresses training, validation, standardization, and technological support, NCCS initiatives can effectively contribute to conservation science, inform policy, and foster greater trust and engagement among all participants (Soria & Tormáné Kovács, 2025)

2.7. Nature Conservation dimension of NCCS projects

The nature conservation dimension of NCCS projects refers to their direct and indirect contributions to biodiversity protection, ecosystem management, and conservation policy (McKinley et al., 2017; Fraisl et al., 2022). This approach enables the gathering of spatially extensive and long-term databases that would otherwise be difficult or prohibitively expensive to obtain through conventional scientific methods alone (Bonney et al., 2014; Pocock et al., 2018). By leveraging the collective efforts of citizen scientists, NCCS initiatives fill critical data gaps, enhance the monitoring of biodiversity trends, and contribute valuable information for conservation planning and decision-making (Chandler et al., 2017; Haklay et al., 2018; Kasten et al., 2021).

Contributions to biodiversity monitoring and ecosystem management

NCCS projects have increasingly demonstrated their value in supporting biodiversity conservation by generating extensive ecological data that inform habitat protection, species monitoring, and ecosystem management (McKinley et al., 2017). Volunteers engaged in these projects collect critical information on species distributions, population trends, and habitat changes, which are essential for identifying priority conservation areas and guiding restoration efforts (Dickinson et al., 2012; Pocock et al., 2015; Chandler et al., 2017). Large-scale projects like eBird and iNaturalist have provided databases that help designate protected areas and monitor threatened species, enabling more effective conservation planning (Sullivan et al., 2014; Di Cecco et al., 2021). Cox et al. (2022) combined large-scale species distribution data, much of it contributed by volunteers and citizen scientists, to identify global priority areas for reptile conservation. Their findings show how volunteer-collected data contributes to biodiversity monitoring and can fill critical gaps and directly inform the designation of protected areas for threatened species.

Informing conservation policy and decision-making

Another way NCCS projects influence nature conservation is by informing policy, particularly during the early stages of policy development such as problem identification and agenda setting (Tollington et al., 2017). These projects supply policymakers with valuable data that highlight conservation needs and emerging environmental issues (Chapman & Hodges, 2020), meaning early stages of policy making by providing information (Sullivan et al., 2014; Saunders et al., 2021). However, direct involvement in later policy stages, such as formulation and implementation, is less frequent (Göbel et al., 2019). A few examples reached implementation for instance, the German Mückenatlas project not only informed policy by mapping mosquito distributions but also influenced policy implementation by guiding invasive species control efforts (Pernat, 2022). This pattern is consistent across many

NCCS initiatives, which often aspire to impact policy but face challenges in data sharing and communication with decision-makers (Miller, 2022).

Assessment methods of conservation impact

To evaluate the conservation impact of NCCS projects, researchers commonly use case studies and online surveys (Price-Jones et al., 2022). Case studies provide in-depth analyses of individual projects' contributions to policy and management, while surveys capture broader trends across multiple initiatives (Finch et al., 2022). Some studies apply evaluation frameworks, such as the Telecoupling Framework, to assess how citizen science affects conservation policy by examining complex human-environment interactions (Yang et al., 2019; Wehn et al., 2021). Despite recommendations for more systematic evaluation, only a few projects have employed such frameworks, highlighting an area for improvement in impact assessment (Liñán et al., 2022; Soria & Tormáné Kovács, 2024).

Challenges limiting conservation policy influence

Several challenges hinder the full realization of NCCS projects' potential in conservation policy. The foremost is ensuring data quality; without rigorous validation, policymakers may hesitate to rely on citizen-generated data. Sustained and long-term funding is another critical challenge, as policymakers prefer continuous databases for robust decision-making, yet many projects depend on short-term grants or donations (Price-Jones et al., 2022; Farr et al., 2023).

Another significant challenge faced by NCCS projects is the lack of effective communication channels with policymakers. When project outcomes or data are not adequately shared (such as by failing to upload findings to official databases e.g., GBIF), opportunities for these NCCS results to inform policy and management decisions are missed (Cooper et al., 2012; Suškevičs et al., 2021). This communication gap can hinder the development of trust and reduce the likelihood that valuable citizen-generated data will be translated into actionable conservation policies (Fritz et al., 2022).

Enhancing conservation outcomes

To maximize the conservation impact of NCCS projects, it is recommended to prioritize improving data quality through standardized protocols and expert validation, secure sustained funding to support long-term monitoring, and strengthen collaboration with decision-makers. Establishing guidelines that address the needs of policymakers at different stages of conservation policy development can help NCCS projects better align their objectives with policy processes and increase their influence (Soria & Tormáné Kovács, 2025).

Empirical studies evaluating the nature conservation contribution of NCCS projects

Recent empirical studies have demonstrated that NCCS projects like eBird and iNaturalist are increasingly being evaluated for their effectiveness in supporting conservation policy-making (Ackland et al., 2024; Kelling, 2018). These evaluations often focus on how data contributed by the public is integrated into official decision-making processes, particularly in the context of environmental impact assessments and conservation area designation. McKinley et al. (2017) evaluated the nature conservation outcomes of several CS projects, including COASST (Coastal Observation and Seabird Survey Team), PlantWatch, and the Great Koala Count, through a comprehensive approach combining literature review, expert workshops, case study analysis, and interviews with project leaders and resource managers. Their evaluation focused on tracing the real-world application of citizen-collected data in conservation management, rapid response to emerging threats, restoration planning, and policy decisions. For example, COASST's real-time monitoring data informed agency actions during harmful algal blooms and fisheries bycatch events, while PlantWatch's phenology data contributed to environmental monitoring and habitat management. The Great Koala Count's citizen observations were validated and integrated into species management frameworks, influencing regional conservation priorities. Key factors enabling these outcomes included rigorous data validation, participant training, institutional collaboration, and trust-building between citizen scientists and resource managers. This evaluation demonstrated how well-designed CS projects generate credible data that directly support and accelerate effective conservation actions and policy-making.

Kelly et al. (2020) similarly assessed nature conservation outcomes of marine CS projects. By systematically investigating where citizen-generated data have been incorporated into management plans, biodiversity databases, and policy decisions, the study demonstrates that these projects directly inform and shape conservation strategies. Through detailed case studies of initiatives like Redmap Australia and Snapshot Cal Coast citizen science projects, the authors traced the journey from citizen data collection to validated scientific findings that have influenced on-the-ground conservation actions and adaptive management. Their analysis also mapped out the pathways by which CS translates into practical results (for instance, through integration into official monitoring frameworks, being cited in scientific literature, or contributing to environmental reporting and management decisions).

Importantly, the review spans 74 projects worldwide, underscoring that marine citizen science initiatives are especially valuable for closing critical knowledge gaps in remote marine regions. Projects like Redmap Australia furnish distribution data on marine species that resource managers use to adapt to climate-driven changes, while Snapshot Cal Coast supports the assessment and management of California's Marine Protected Areas using biodiversity data supplied by the public.

Turbé et al. (2020) conducted a comprehensive assessment of European citizen science projects, placing particular emphasis on their tangible nature conservation outcomes, though they also evaluated scientific achievements in parallel. For the conservation dimension, the authors examined whether and how data collected by citizens were applied in conservation practice and policy. Their evaluation criteria included several key aspects: the use of citizen science data in management plans (such as informing local or national actions for habitat protection and restoration), the integration and validation of data within official or public biodiversity databases (crucial for monitoring and reporting), and the influence of these data in policy and compliance contexts (like helping designate protected areas, supporting EU directive assessments, or triggering responses to environmental incidents). They also measured whether citizen science results were incorporated into government or EU environmental reports, providing large-scale insights and guiding progress toward policy targets.

To evaluate these outcomes, Turbé et al. (2020) systematically analysed project documentation, surveyed project coordinators, and tracked specific examples where data collection led to documented impacts on conservation practice or policy. They highlighted cases in which citizen science enabled the early identification of environmental issues that spurred policy responses or addressed monitoring obligations under European legislation. Their findings revealed that while the potential for citizen science to achieve real conservation impacts is strong, successful uptake depends largely on data quality standards, effective collaboration with authorities, and the existence of formal procedures for integrating citizen-generated data into environmental management and policy frameworks.

2.8. Participants' development dimension of NCCS projects

NCCS projects have a significant influence on the development of their participants (Turrini et al., 2018). Studies using participants' surveys have shown that involvement in NCCS projects can foster improvements in participants' knowledge about nature, attitudes toward conservation, and pro-environmental behaviours. These impacts are observed before and after participation, demonstrating that such projects can effectively support learning, positive attitude shifts, and behavioural change related to nature conservation (Soria & Tormáné Kovács, 2023).

Knowledge and skills acquisition

Many NCCS projects help volunteers expand their understanding of species and improve their ability to identify them (Von Gönner et al., 2024). Most studies assessing knowledge outcomes among NCCS participants find that volunteers typically improve their understanding of specific species and develop stronger identification skills (Bonney et al., 2009). However, fewer participants report gaining a deeper understanding of knowledge related to science as a result of their involvement (Phillips et al., 2018; Ng et al., 2023). Projects that incorporate a range of educational resources (such as printed guides, interactive applications, and hands-on training) are generally more successful at fostering participant learning. For example, Hitchcock et al. (2021) highlight how the use of diverse tools and technology platforms like iNaturalist and Zooniverse can significantly enhance learning outcomes in citizen science initiatives. Furthermore, opportunities for social interaction with project leaders and fellow volunteers, as well as constructive feedback, can reinforce these learning outcomes and enhance scientific literacy (Jordan et al., 2011; Shah & Martinez, 2016; Tang et al., 2021).

Attitudinal changes

Participation in NCCS initiatives often leads to more positive attitudes towards nature and conservation (Santori et al., 2021; Soria & Tormáné Kovács, 2023). Individuals who initially felt uneasy or indifferent about certain species may develop appreciation and empathy after engaging with a project (Roy et al., 2016; Dayer et al., 2019). Positive emotional experiences, such as enjoyment and fascination, are frequently reported and can foster a stronger connection to nature (Crall et al., 2013; Leonard et al., 2023). However, shifts in attitudes towards science itself are less common, suggesting that more comprehensive involvement in the research process may be needed to influence views on science more broadly (Haklay, 2013; Shah & Martinez, 2016).

Behavioural shifts

NCCS projects are widely recognized for their ability to foster meaningful behavioural shifts among participants (Peter et al., 2019), encouraging actions that benefit nature (Maynard et al., 2020; Santori et al., 2021) and promoting environmental stewardship (Church et al., 2025). These behavioural changes might be translated into concrete conservation actions, such as habitat restoration (Santori et al., 2021), replacing invasive plants with native species (Ganzevoort & van den Born, 2021; Peter et al., 2021), sharing knowledge (Jordan et al., 2011), or adopting environmentally friendly habits like reducing litter during outdoor activities (Chao et al., 2021; Day et al., 2022). Evidence shows that NCCS participation provides experiential learning, deepens connectedness to nature, and empowers volunteers by allowing them to see the tangible impacts of their efforts when collecting data, which are key elements that drive long-term stewardship behaviours (Olson & Colston, 2024).

To promote meaningful behavioural change among participants, research highlights the importance of designing NCCS initiatives with intentional strategies that build trust, foster community, and create strong collaborations between scientists, NGOs, and citizens (Amauchi et al., 2022). When participants develop a genuine appreciation for nature through these experiences, they are more likely to modify their behaviour positively towards nature conservation (Richardson & Sheffield, 2017; Leonard et al., 2023).

Environmental stewardship, as an extension of these behavioural shifts, involves a broader cultural and ethical commitment to caring for the environment (Mathevet et al., 2018). NCCS projects contribute to this by nurturing a sense of responsibility and agency among participants, motivating them to take ongoing conservation actions beyond the project itself (Church et al., 2025). This stewardship is characterized by sustained engagement, advocacy for environmental protection, and participation in community-based resource management, all of which are essential for achieving lasting conservation outcomes (McKinley et al., 2017; Olson & Colston, 2024).

Project characteristics that support participants' development

Projects that are most successful in fostering participants' development tend to share several characteristics (Soria & Tormáné Kovács, 2023):

- They offer well-structured educational plans and diverse training opportunities.
- They encourage social connections and collaboration among participants and with experts.
- They build trust through personalized feedback, recognition of volunteer efforts, and ongoing communication.
- They often collaborate with schools or other organizations to strengthen knowledge transfer and long-term engagement

These features not only strengthen learning and foster positive changes in attitudes, but also encourage lasting pro-environmental behaviours. Therefore, incorporating these elements is recommended as a best practice when designing and implementing future NCCS projects, ensuring that the participants' development dimension is valued just as highly as other dimensions (science and nature conservation).

Empirical studies evaluating the participants' development of NCCS projects

A widely cited study evaluating participant outcomes in CS projects is by Peter et al. (2021). They surveyed 917 participants from biodiversity citizen science projects across 34 countries to measure how involvement affected participants' knowledge, attitudes, behaviours, skills, self-efficacy, and interest. They found that most participants reported significant learning about species and the environment, increased interest in biodiversity and science, and examples of behavioural changes such as adopting wildlife-friendly gardening or engaging more in conservation activities. The study combined surveys and qualitative responses, showing that well-designed projects can boost understanding, positive attitudes, and conservation actions among participants. The authors recommend using common frameworks and long-term studies to better track these impacts.

A study by Hsu et al. (2025) evaluating the Taoyuan Algal Reef CS project in Taiwan explored how participation influenced the knowledge and attitudes of volunteers. With 245 participants, the research utilized pre- and post-project surveys to assess changes across these dimensions. The results revealed that while increased environmental knowledge and a stronger connection to the local reef were both important, the development of positive attitudes toward conservation served as the key factor mediating participants' intentions to act. In other words, the study found that knowledge and sense of place only led to meaningful changes in behavioural intention when they contributed to more favourable attitudes toward biodiversity. The project also promoted learning and a sense of personal accomplishment among participants, which further reinforced positive attitudes and the motivation to continue conservation efforts. These findings underscore the importance of designing NCCS initiatives that not only deliver information but also actively cultivate positive attitudes and meaningful engagement, as these are essential for fostering sustained conservation action.

Brossard et al. (2005) evaluated knowledge and attitude changes in the context of The Birdhouse Network, a citizen science project of the Cornell Lab of Ornithology. The authors used a rigorous quantitative approach, featuring a pre- and post-test non-equivalent groups design. Participants received a survey before starting the project (pre-test) and at the end of the field season (post-test). Control groups of Cornell Lab members who did not participate in The Birdhouse Network project were also surveyed.

The survey measured key outcomes: bird biology knowledge (via content questions), attitude toward science (using ATOSS - Attitudes Toward Organized Science Scale), environmental attitude (via the New Environmental Paradigm - NEP scale), and understanding of the scientific process (through both closed and open-ended questions). Quantitative data were analysed statistically, and qualitative responses were assessed as well. Results showed that while participants' knowledge of bird biology increased significantly, their attitudes toward science and the environment, as well as their understanding of the scientific process, did not change measurably. The evaluation highlighted the need for more sensitive tools to assess the broader impacts of citizen science, especially in attitudes and understanding of scientific methods.

In the study by Santori et al. (2021), participants' behaviour was measured using an online questionnaire administered to the TurtleSAT NCCS project, which aims at data collection for freshwater turtle conservation. The survey asked participants not only about their knowledge and skills regarding turtles but also whether and how their behaviours and attitudes had changed after contributing data through the app. Key behavioural changes were self-reported and included adopting more turtle-friendly practices (such as engaging in habitat restoration, moving turtles out of harm's way, and an increased concern for turtle conservation). The study quantified these outcomes by asking respondents whether they had learned more about turtles, improved their ability to identify species, and taken actions that directly benefit turtle conservation. Results show that 70% of participants claimed to have learned more about turtles through the app, and nearly half reported an improvement in their species identification skills. Furthermore, 84% felt their participation helped turtles, and 70% felt greater concern for turtle conservation. These self-reported behavioural and attitudinal changes were then analysed to identify associations with increases in knowledge and skills gained through the citizen science project. Analysis revealed that participants who reported greater knowledge and improved identification skills through the project were also more likely to adopt turtle-friendly behaviours and display increased concern for turtle conservation. The authors noted the importance of interpreting these results cautiously since behaviour and attitude changes were based on self-reported data, but they highlight the potential positive conservation impacts of engaging the public through NCCS projects like TurtleSAT.

3. MATERIALS AND METHODS

3.1. Study design and development

Prior to the empirical application, based on an extensive literature review (full references Table 5), a three-dimensional conceptual framework was developed as the foundation for evaluating NCCS projects across three core dimensions: science, nature conservation, and participants' development (Objective 1; Q1.1).

Building on the conceptual framework, a three-dimensional evaluation framework was designed as an operational tool (Objective 1; Q1.2) to evaluate selected NCCS projects. Each component of the framework was translated into clear, binary criteria questions, enabling systematic and comparable evaluation. While empirically tested in the Hungarian NCCS context, the framework itself is not country-specific and can be adapted for use in other nations.

To define the NCCS projects selected for evaluation, a desktop study was conducted to identify the universe of NCCS initiatives in Hungary, applying predefined inclusion criteria and inviting project coordinators to participate (interviews), resulting in eight projects for the qualitative assessment through the three-dimensional evaluation framework. The evaluation drew on qualitative content analysis of interviews conducted among project managers/coordinators of the selected NCCS projects (detailed procedure in section 3.4).

To extend the qualitative evaluation, a comparative focus analysis of two NCCS projects was conducted, supplying empirical insight into components of the science and participants' development dimensions. Specifically, the science dimension was examined through a comparative analysis of observation data of two selected NCCS projects, while the participants' development dimension was examined through the comparative analysis of questionnaire surveys conducted among participants of two selected projects. This dual analysis provided a deeper and focused examination of the research questions associated with Objectives 2 and 4 (Q2.1–Q2.2; Q4.1 to Q4.3), complementing the framework-based evaluation. It also strengthened the study by incorporating participants' first-hand perspectives, thereby balancing the earlier framework that primarily reflected project managers' viewpoints with evidence from volunteer experiences and responses.

The Amphibian and Reptile Mapping and the WildWatcher were chosen as two NCCS projects for deep-focused analysis. They were selected based on their comparable characteristics, including time scope, data collection protocol, data availability, and flexibility of project managers (detailed procedures are provided in section 3.5).

Overall, the study employed a mixed-methods approach structured into three sequential phases aligned with the components of the three-dimensional conceptual framework (Figure 2):

- Phase 1: qualitative evaluation of eight NCCS projects via semi-structured interviews (Objective 1 to 4)
- Phase 2: comparative analysis of long-term observation databases from two projects to examine data quality practices and scientific robustness, and to evidence monitoring/management relevance (Objective 2; Q2.1–Q2.2)
- Phase 3: comparative analysis of participant surveys from two projects to assess motivation, knowledge, and attitudes/behaviours (Objective 4; Q4.1 to Q4.3).

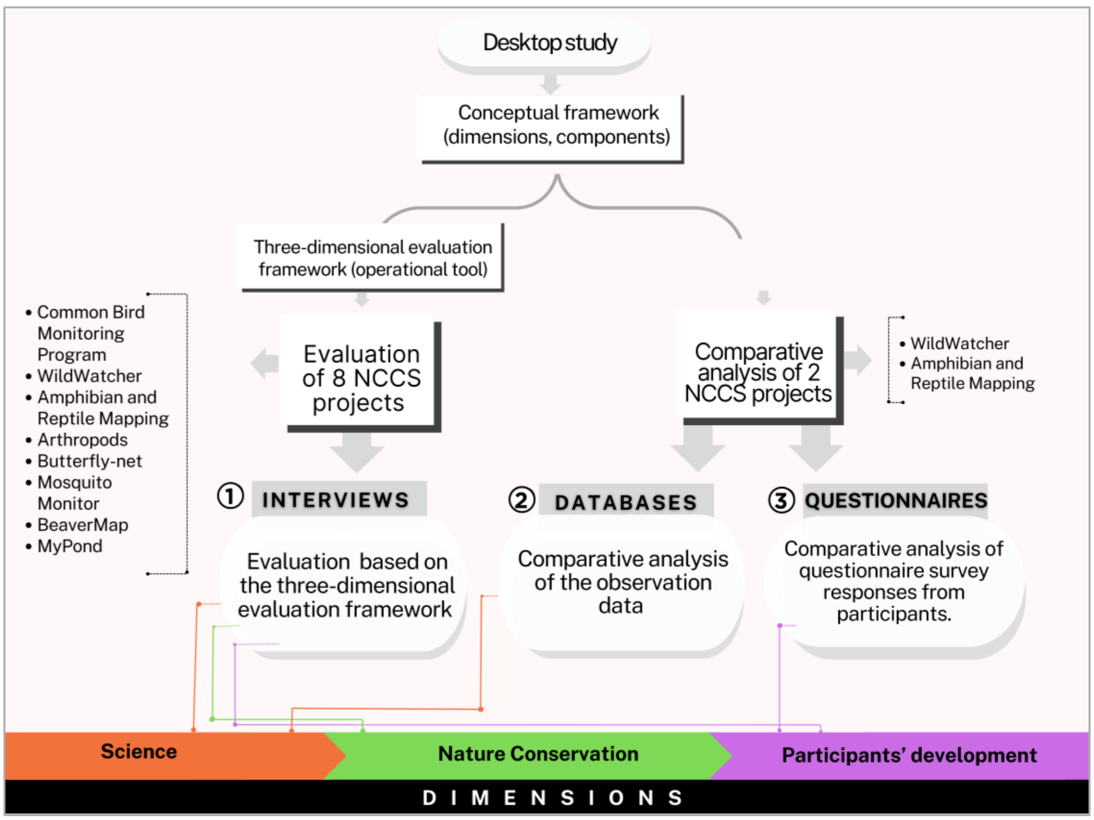

Figure 2. Mixed-methods, three-dimensional evaluation design

By employing this dual qualitative-quantitative strategy (Creswell & Plano, 2018), this mixed-methods design provides an integrated, generalizable evaluation of NCCS performance across science, nature conservation, and participants' development, and the next sections detail each phase of the Figure 2 in turn.

3.2. Conceptual three-dimensional framework for NCCS projects

A comprehensive three-dimensional conceptual framework was designed by drawing on a wide range of citizen science literature (see Table 5 for references), including established evaluation approaches and recommendations for enhancing project effectiveness. This three-dimensional conceptual framework served as the foundation for the subsequent three-dimensional evaluation framework (explained in section 3.3), both of which were specifically designed for NCCS projects. While it is not country-specific, it was empirically tested within Hungarian NCCS projects to assess its applicability in that context. At the core of the conceptual framework are three essential dimensions: science (e.g., data quality, validation, data management), nature conservation (e.g., use of data in monitoring and management), and participants' development (e.g., training, knowledge gain, behavioural and attitude change), each comprising key components (Figure 3).

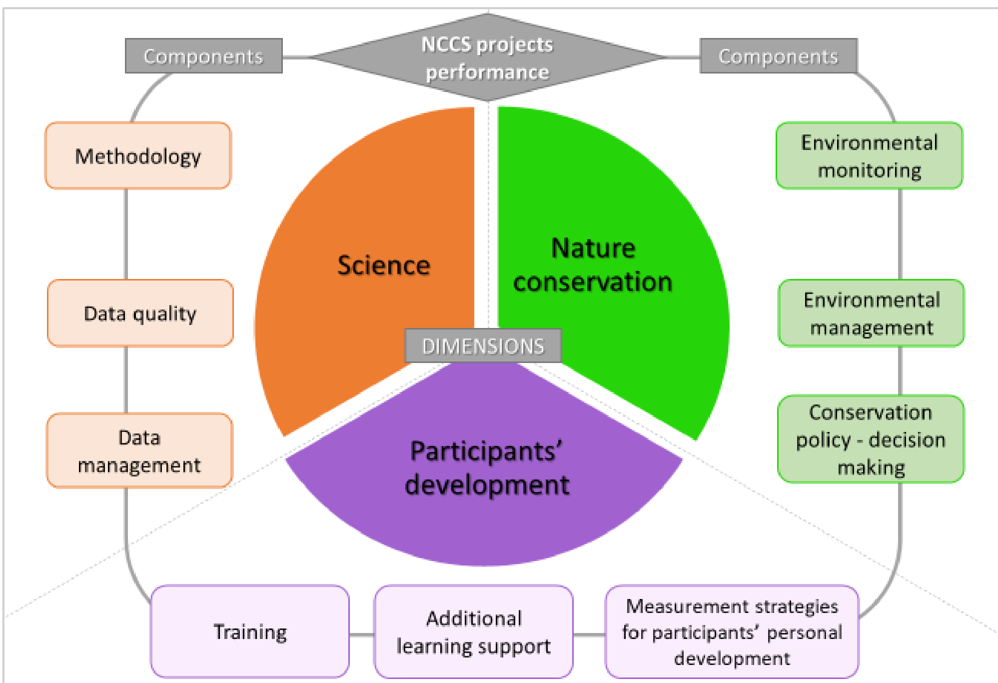

Figure 3. Conceptual framework

The inclusion of the scientific dimension addresses ongoing debates about the reliability and impact of citizen science data and outputs (Balázs et al., 2021; Farr et al., 2023). NCCS's primary objective is advancing the conservation of species, ecosystems, and natural resources (McKinley et al., 2017; Suškevičs et al., 2021), which is why the nature conservation dimension is a key component of the framework. And the addition of the participants' development dimension reflects growing recognition in recent research that volunteer involvement can positively influence individual development (attitude, behaviour change) and learning (Turrini et al., 2018; Santori et al., 2021).

To make the conceptual framework actionable and keep it aligned with the study objectives, each research question was mapped to the relevant dimensions and components of the framework, guiding instrument design, data collection, and analysis as shown in Table 4.

Table 4. Alignment of research questions with conceptual framework components

Dimensions	**Research question**	**Components**	**Research question**
Science	1.1 What are the key components of a three-dimensional conceptual framework for evaluating NCCS projects in a broader country scope?	Methodology	2.1 How do NCCS projects ensure data quality?
		Data quality	2.1 How do NCCS projects ensure data quality?
		Data management	2.2 Are the outcomes of NCCS projects scientifically robust?
Nature conservation	1.2 How can these components be translated/operationalized into a practical, user-friendly three-dimensional evaluation framework for NCCS projects' performance assessment?	Environmental monitoring	3.1 How can NCCS projects contribute directly to the monitoring of species?
		Environmental management	3.2 How are NCCS projects' outcomes utilized in species management?
		Conservation policy – decision making	3.3 How are NCCS project outcomes utilized in policies and conservation actions?
Participants' development		Training	4.2 How do NCCS projects influence the knowledge of participants?
		Additional learning support	4.2 How do NCCS projects influence the knowledge of participants?
		Measurement strategies for participants' personal development	4.1 What motivates citizens to get involved in the selected NCCS projects? 4.3 How do NCCS projects influence participants' attitudes and behaviors?

3.3. Development of the three-dimensional evaluation framework for NCCS projects

To facilitate a clear and comprehensive comparison of project performance across the three key dimensions (science, nature conservation, and participants' development), the three-dimensional conceptual framework was operationalized into a three-dimensional evaluation framework using assessment criteria grounded in each component (three per dimension) and widely supported by the literature (see Table 5 for detailed references). The criteria set, thus, represents a practical extension of the conceptual framework, linking criteria concepts to measurable and actionable assessment items tailored to capture the specific characteristics of each dimension. The differing number of criteria per dimension reflects the unique complexity and scope of each component, ensuring that all significant aspects are adequately covered.

For each criterion, we formulated clear and concise yes/no questions to operationalize the framework effectively. These questions reflect key topics and concerns extensively addressed in the literature and are documented for each criterion in Table 5.

Table 5. Assessment criteria of the three-dimensional evaluation framework for NCCS projects across three key dimensions

Component	**Criteria for the assessment**	**References**	**Criteria questions**	**No = 0, Yes = 1**
Science dimension				
Methodology	Research question	McKinley et al. 2017.	Was a scientific question formulated before starting the project?	
	Methodology for data collection	Kosmala et al. 2016; Stevenson et al. 2021).	When recording an observation, is supporting information (e.g., a photograph, videos) mandatory to upload as part of the data collection methodology?	
	Technology use	Serrano-Sanz et al. 2014; Kosmala et al. 2016; Freitag et al., 2016.	Does the project require the use of technology that supports data collection and data quality? (e.g., smartphones, tablets, sensors)	
Data quality	Data validation	Wiggins et al. 2011; Freitag et al. 2016.; Balázs et al. 2021	Are protocols for data collection tested and validated before starting the project, in order to ensure data quality?	
		Wiggins et al. 2011; 2013; Kosmala et al. 2016; Freitag et al. 2016; McKinley et al. 2017	Do they have an effective strategy for data quality assessment? (e.g., specialized professionals involved, request of more information to participants, site visits)	
	Institutional affiliation	Freitag et al. 2016; Turbé et al. 2019	Is the project formally connected to a larger scientific or conservation organization?	
Data management practices	Long-term databases	McKinley et al. 2017	Does the project have long-term databases?	
	Open data	Murray-Rust 2008; McKinley et al. 2017	Is there any summary of the data collected released for the public? (e.g., summaries in the form of maps, charts, statistics)	
		Wiggins et al. 2013; Freitag et al. 2016	Are data stored in suitable repositories? (e.g., the General Data Protection Regulation [GDPR] considered)	
		Murray-Rust 2008	Are complete or partial databases publicly available for download?	
	Publications	Freitag et al. 2016; Bio Innovation Service 2018; McKinley et al. 2017; Turbé et al. 2019	Have the findings/data been published in peer-reviewed academic journals? (For example, has the collected data been used in scientific publications or cited in academic journals or scientific books?)	
Nature conservation dimension				
Environmental monitoring	Data use in species/ ecosystem monitoring	McKinley et al. 2017	Has the data collected by volunteers through the project been used for species or ecosystem monitoring?	

Component	Criteria for the assessment	References	Criteria questions	No = 0, Yes = 1
Environmental management	Data use in species/ ecosystem management	McKinley et al. 2017; Maynard et al. 2020; Kelly et al. 2020.	Has the data collected by volunteers through the project been used for species or ecosystem management?	
Conservation policy-making	Data use in conservation policy making	McKinley et al. 2017; Turbé et al. 2019; Suškevičs et al. 2021	Has the data collected through the project influenced policy decisions at the local, national, regional, or European Union level?	
Participants' development dimension				
Training	Forms of training provided	Turbé et al. 2019; Phillips et al. 2018	Is personal training provided to the participants?	
		Turbé et al. 2019	Is any other form of training/knowledge transfer provided to the participants? (e.g., written guidelines, videos, an informative phone application, or website)	
Additional learning support	Educational events	Serrano-Sanz et al. 2014	Are events to support learning and promote environmental education organized?	
	Communication for gaining knowledge	Brossard et al. 2005	Are there ways to connect with available experts who can answer participant questions and resolve issues? (e.g., via email, social media, app chat)	
Measurement strategies for participants' personal development	Measurement of knowledge gained/reinforced	Maynard et al. 2020; Santori et al. 2021; Brossard et al. 2005; Jordan et al., 2011; Phillips et al. 2018	Is the participants' knowledge assessed? (e.g., species recognition, knowledge about the species ecology, conservation knowledge)	
	Measurement of skills - gained/reinforced	Maynard et al. 2020; Santori et al. 2021; Phillips et al. 2018	Are participants' skills assessed? (e.g., using equipment, data collection protocol)	
	Measurement of attitude/ behavioral change	Somerwill & Wehn, 2022; Maynard et al. 2020; Santori et al. 2021; Brossard et al. 2005; Jordan et al. 2011; Phillips et al. 2018	Are participants' attitudes/behavior assessed?	
	Strategies for reinforcing and increasing knowledge through feedback	Cox et al., 2022; Ceccaroni & Piera, 2017; Tang et al., 2021	Do participants receive feedback that reinforces their knowledge, such as in-person, email, or app-based responses?	

Each project was then evaluated within the three focal dimensions using a binary scoring system: a score of 1 ("yes") indicates the criterion was met, and 0 ("no") indicates it was not. Because each dimension (science, nature conservation, participants' development) was assessed using a different number of criteria questions, direct comparison of total scores across these areas would not have been meaningful. To address this, we applied the Relative Percentage of Maximum (RPM) normalization method. This approach involved calculating each project's score for a given dimension as the maximum possible score in that dimension. Specifically, for each dimension, the sum of "yes" (1) answers achieved by a project was divided by the total number of criteria for that dimension, and then multiplied by 100 to yield a normalized score point. This normalization enabled fair, interpretable comparisons across projects and dimensions, regardless of the absolute number of criteria, and ensured that our holistic assessment accurately reflected relative performance. The normalized score for dimension i is calculated using the formula:

$$Normalized\ score_i = \frac{Total\ points\ _i}{Maximum\ total\ \ points\ in\ dimension} \times 100$$

Where Total points $_i$ is the total points of projects in a specific dimension. This process ensures that the project with the maximum possible points in a dimension is represented as 100, and all other projects' points reflect their performance as a proportion of the maximum achievable points. This normalization preserves the relative differences in performance without reducing the lowest scores to zero unless a score of zero was observed. The resulting normalized scores were used for further comparisons of the projects. This normalization enabled fair, interpretable comparisons across projects and dimensions, regardless of the absolute number of criteria questions, and ensured that our holistic assessment accurately reflected relative performance.

3.4. Evaluation of selected Hungarian NCCS projects in the three-dimensional framework

Scope of the evaluation of selected Hungarian NCCS projects

The list below shows the connection between the evaluation of selected Hungarian NCCS projects based on the three-dimensional framework, described in this section, with objective (Q1.1–Q4.3), and demonstrates the framework's coverage across all three dimensions:

- Addresses Objective 1 (Q1.1–Q1.2) by applying the conceptual framework and its operationalized criteria to real projects, empirically assessing NCCS projects in Hungary, thereby validating component coverage and the practicality of the binary scoring instrument.
- Addresses Objective 2 (Q2.1–Q2.2) by producing evidence on the science dimension, including data collection protocols, validation, data management, open data, and data management in publication production.

- Addresses Objective 3 (Q3.1–Q3.3) by documenting how project outputs are used in species/ecosystem monitoring, management decisions, and conservation policy/decision-making, producing evidence on the nature conservation dimension
- Addresses Objective 4 (Q4.1–Q4.3) by capturing provisions for training, learning supports, measurement of knowledge/skills/attitudes/behaviours, feedback mechanisms, and insights into participants' development dimension.

NCCS projects identification and screening

A desktop study (2021) surveyed official citizen science platforms and the websites of research institutes, universities, and citizen science associations (e.g., ECSA) to identify NCCS initiatives operating in Hungary. Fifteen projects were identified that met three inclusion criteria: being initiated in Hungary, having a primary focus on nature conservation or biodiversity, and targeting either flora or/and fauna species. Project coordinators/managers were invited to participate in the study; nine coordinators agreed. One project was excluded because its activities and governance were determined to be foreign in origin. Therefore, the remaining eight NCCS project constituted the final evaluation sample. This selection ensured a diverse representation in terms of project types, geographic distribution, institutional affiliations, and target taxa, thus allowing for a comprehensive exploration of both common trends and unique challenges within the Hungarian NCCS context.

Data collection for the eight NCCS projects

From April to July 2022, eight semi-structured interviews (Newing et al., 2011) were conducted with coordinators of NCCS projects in Hungary (six via online and two in person). The semi-structured interviews were chosen because they offer the flexibility to explore participants' perspectives in depth while maintaining a consistent framework for comparison across interviews, allowing both guided discussion and the opportunity to pursue unexpected insights. These interviews aimed to gain detailed insights into the experiences and viewpoints of professionals overseeing NCCS initiatives.

The interviews were organized into five thematic blocks: (1) project description, (2) science dimension, (3) nature conservation dimension, (4) participants' development, and (5) outcomes and challenges (see Appendix 1). This structure allowed for a systematic exploration of each project's objectives, methodologies, participant engagement strategies, and perceived impacts, while also providing space for NCCS project managers to discuss challenges and lessons learned.

The in-person interviews were recorded using a digital voice recorder (Olympus WS-832), whereas online interviews were conducted through the Skype platform with built-in recording functionality. Throughout the interviews, notes were taken, and all recordings were transcribed *verbatim* using MAXQDA software (VERBI, 2021). On average, each interview lasted around 80 minutes; the shortest session was 60 minutes, while the longest extended to 120 minutes and was conducted over two days due to the interviewee's schedule.

Data analysis based on the three-dimensional evaluation framework

Following our conceptual framework, a systematic analysis of the interview transcripts using qualitative content analysis was performed (Elo & Kyngäs, 2008; Mayring, 2021). Initially, a set of *a priori* codes was developed, reflecting the main project characteristics (including aim, institutional affiliation, target species, periodicity, geographical scope, participant tasks, number of participants, and total observations up to 2022 records) and each dimension of the three-dimensional evaluation framework. These codes were applied to the interview transcripts using MAXQDA software (VERBI 2021), which facilitated systematic organization, retrieval of relevant data segments, and subsequent qualitative content analysis.

Detailed information about each project was then summarized in Excel tables, capturing the core characteristics and main topics within each dimension. Project performance was evaluated by answering the specific yes/no criteria related to the conceptual/evaluation framework, directly referencing the relevant coded interview data, thereby linking qualitative insights with quantitative scoring. To each project, binary scores (1 for "yes," 0 for "no") were assigned across all criteria, which were summed within each dimension and normalized to enable fair comparisons across diverse criteria sets. To deepen the interpretation of the results, qualitative content analysis was also employed, using interview excerpts and descriptions to contextualize and illustrate the strengths and limitations revealed by the scoring. Although the content analysis and evaluation reflect the state of these NCCS projects as of 2022, it is noted that several projects have since evolved, and these developments are acknowledged. The combination of qualitative data and quantitative scoring not only enhanced the transparency and robustness of the assessment but also provided a nuanced context for interpreting the results, with interview excerpts revealing factors behind each project's strengths and challenges. This method ensures that the evaluation is both comprehensive and deeply reflective of the projects' real-world conditions, capturing the complexity of citizen science initiatives as documented in the interviews

Ethical considerations for the data collection and evaluation of the eight NCCS projects using the three-dimensional evaluation framework

Throughout the interview process, we adhered to the ethical guidelines set by the Code of Research Ethics of the Hungarian Academy of Sciences (HAS Hungarian Academy of Science, 2010) and the European Code of Conduct for Research Integrity (ALLEA, 2017). Prior to each interview, participants provided written informed consent, which covered aspects such as data usage, confidentiality, anonymity, voluntary participation, recording permission, and assurance of no harm.

3.5. Comparative analysis of observation data of two Hungarian NCCS projects

Scope of the comparative analysis of observation data

The following list shows alignment of the section of the comparative analysis of observation data of two Hungarian NCCS projects with Objective 2 and demonstrates coverage across the science dimension of the framework:

- Addresses Objective 2 (Q2.1–Q2.2) by examining how projects ensure data quality and assessing the scientific robustness of outcomes using long-term observation records from two NCCS projects.
- Provides complementary, data-driven indicators for the science dimension of the three-dimensional conceptual framework

Selection of observation databases

For this study, two observation databases from Hungarian NCCS projects were selected based on comparability and accessibility, identified during the first phase of evaluation of eight NCCS initiatives in Hungary. The projects were chosen according to the following criteria: (i) both focus on specific and well-defined taxonomic groups, (ii) both employ similar protocols for data collection by participants, and (iii) both cover a comparable temporal scope. A further consideration was the willingness and availability of the respective project managers to provide full access to the observation data. In 2025, project managers of both NCCS initiatives provided the complete observation datasets via email, covering the full period from each project's launch to the date of transfer.

Characteristics of the observation databases from two NCCS projects

The WildWatcher project and the Amphibian and Reptile Mapping Project. The WildWatcher project, coordinated by the Herman Ottó Institute NGO Ltd. – Vadonleső Group, has been active since 2009 and focuses on monitoring easily identifiable, pre-selected plant and animal species. Their database comprised 17,635 records. The Amphibian and Reptile Mapping Project, managed by the Amphibian and Reptile Protection Department of MME BirdLife Hungary, has operated since 2011 and concentrates on herpetofauna species, whose database contains 74,422 records.

Both databases consist of structured, time-stamped entries representing individual species observations. Data fields include species identification (Latin and common names), observer information (name, user ID), geographic coordinates (latitude and longitude), date and time of observation, as well as contextual variables such as habitat, observation method, and additional comments. Each record is further annotated with validation status, record status (e.g., alive), and metadata related to data entry (e.g., mobile or web platform, photo evidence, validation date, and user). The analysis focused on data collected from the launch dates of each project: 2009 for WildWatcher and 2011 for Amphibian and Reptile Mapping. Although both databases included a few earlier records (one WildWatcher entry from 1990 and three Amphibian and Reptile Mapping entries from 1900), these were excluded to ensure consistency. For both projects, only observations recorded up to December 2024 were included, allowing for the use of complete annual datasets.

Data analysis of the observation data from two Hungarian NCCS projects

For the analysis of the Amphibian and Reptile Mapping and WildWatcher project databases, descriptive statistics and frequency distributions for key variables (number of observations recorded per species and per year, validation status) were conducted with the assistance of the SPSS software (IBM Corp, Version 29.0). To compare the projects, we performed Chi-square and Fisher's exact tests with significance set at $p < .05$, to identify significant differences between categorical variables. Additionally, we calculated Cramer’s V value to assess the strength of any observed difference. We also examined trends in the usage of project interfaces over time. This approach enabled us to systematically assess patterns in data collection, participation, and species reporting, providing a robust foundation for evaluating the scientific and conservation value of these long-term NCCS databases.

Ethical considerations in the comparative analysis of observation data from two NCCS projects

When analysing data from the two NCCS projects, strict adherence to the European Code of Conduct for Research Integrity (ALLEA, 2017) was maintained. The project managers ensured full compliance with GDPR (European Parliament and Council of the European Union, 2016) by carefully anonymizing all personal data and withholding sensitive information such as observers’ email addresses and precise geolocations. This procedure protected participant privacy, upheld legal and ethical standards, and fostered trust between participants and project staff. Such data stewardship underscores the project’s commitment to ethical research and responsible data management practices.

3.6. Comparative analysis of participant questionnaires from two Hungarian NCCS projects

Scope of the comparative analysis of participant questionnaires from two Hungarian NCCS projects

The following list shows the link between the comparative analysis of the two questionnaires' responses from participants in two Hungarian NCCS projects with Objective 4 and demonstrates coverage across one framework dimension:

- Addresses Objective 4 (Q4.1–Q4.3) by comparing participant motivations, knowledge, and attitudes/behaviours across two NCCS projects.
- Provides complementary evidence for the participants' development components of the three-dimensional conceptual framework.

Characteristics of the two questionnaires conducted among the participants of the two NCCS projects

In 2023, two questionnaire surveys were conducted targeting participants of the Amphibian and Reptile Mapping and WildWatcher NCCS projects. Each questionnaire consisted of thirty-one items, organized into four thematic blocks: (1) participation experience and technology use, (2) knowledge gain, (3) motivation, attitude and behaviour, and (4) demographic information. The surveys included a combination of multiple-choice and Likert scale questions. Most questions were identical across both projects to facilitate direct comparison, although a few items were customized to reflect project-specific features such as interface design and content (see Appendix 2).

The questionnaires were originally drafted in English and then translated into Hungarian to ensure clarity and accessibility for participants. The translated versions were reviewed and validated by the project managers of both initiatives. Google Forms was used to send the questionnaires to participants as the survey platform offers accessibility and a user-friendly interface. They were distributed between March and July 2023 for Amphibian and Reptile Mapping, and from June to November 2023 for WildWatcher, using private mailing lists and official project email addresses. An informed consent statement was included at the start of each questionnaire, and only respondents who agreed to participate were allowed to proceed.

Data preparation and cleaning of participant questionnaire surveys from two NCCS Projects

Following data collection, responses were imported into Microsoft Excel for translation verification, cleaning, and organization. The cleaning process involved identifying and addressing missing values, outliers, and inconsistencies to ensure data quality. Questions unique to each project, primarily those related to specific interface features, were excluded from the comparative analysis, except for a few high-frequency responses retained for descriptive purposes. The cleaned databases from both projects were merged, with an additional variable added to indicate the project source of each response. To ensure that higher scores consistently reflected greater knowledge gain or attitude change, we applied reverse scoring (Suárez-Álvarez et al., 2018) to Likert scale responses for items such as "I had sufficient knowledge before participating in the project; my knowledge has not changed" and "My attitude towards nature has not changed. I have behaved in a nature-friendly way before the project." In these cases, responses indicating strong agreement were assigned lower values, so that all items aligned in the same direction for analysis, with higher values always representing greater improvement or change. Expertise-related questions were recoded to classify respondents as "Expert" or "Non-expert" based on their self-reported knowledge of relevant species.

Data analysis of the two questionnaires conducted among the participants of the two NCCS projects

Statistical analyses were conducted using appropriate tests based on the nature of the data. Categorical variables were compared between projects using Chi-square tests or Fisher's exact tests, with significance set at ($p<.05$). When significant associations were found, Cramer's V was calculated to measure the strength of these relationships, with categories combined as needed to ensure valid testing, particularly for questions on observation frequency, interface use, gender, and age.

Likert scale items assessing knowledge, motivation, attitude, and behaviour were first tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests, confirming non-normal distributions. Consequently, the Mann-Whitney U test was employed to compare responses between projects, supported by boxplot visualizations of medians and interquartile ranges.

Ethical considerations in the comparative analysis of the two questionnaires conducted among the participants of two NCCS Projects

The two questionnaires adhered to the European Code of Conduct for Research Integrity (ALLEA, 2017) and the ethical principles of social research (Earl Babbie, 2013; Creswell & Plano, 2018), ensuring that all ethical standards were carefully observed throughout the research process. Informed consent was obtained from every participant prior to data collection, emphasizing transparency and respect for individual autonomy. For the two questionnaires, formal ethical approval was obtained from the contributor, reinforcing our commitment to upholding ethical research practices.

3.7. Challenges and mitigation

Different challenges arose during the research process. The language barrier required careful translation and back-translation of interview and survey materials to preserve meaning. This was addressed through the validation of the questionnaire surveys by project managers and the research supervisor. Second, recruiting participants for the questionnaires required sending personalized email invitations through each NCCS initiative, and multiple reminders were often necessary to achieve a sufficiently representative response rate and encourage participation. These mitigation strategies helped to ensure the integrity and inclusivity of the research process.

3.8. Limitations

Online sampling and coverage. The participant survey was administered online via project mailing lists, relying on self-selection and self-report; this likely underrepresents individuals who are less active online or not on mailing lists and may increase selection bias relative to the wider NCCS population.

Although most items were multiple choice or Likert scale, some open-ended responses allowed descriptive text; these Hungarian texts were translated by a non-native speaker during data cleaning, so nuanced meanings may have been lost or misinterpreted, introducing potential measurement error in the qualitative content used for interpretation.

4. RESULTS AND DISCUSSION

4.1. Results of the three-dimensional evaluation of selected NCCS projects

4.1.1. Overview of evaluated NCCS projects in Hungary

The characteristics of NCCS projects in Hungary are diverse, reflecting a range of features, objectives, and organizational structures (Table 6). While all projects share the common goal of data collection of species (and in the case of MyPond, also ecosystems), not all were initially conceived as NCCS initiatives. For example, WildWatcher began as a scientific monitoring effort within the Hungarian Biodiversity Monitoring System in 2009, evolving from its predecessor, the Squirrel Watcher Program. It was only later that the project team recognized their work as citizen science. Similarly, the Amphibian and Reptile Mapping Project only identified itself as an NCCS initiative after attending a citizen science session at the 2012 European Conservation Biology Conference in Glasgow. In contrast, projects launched within the past five years, such as MyPond, BeaverMap, and the Mosquito Surveillance Project, were designed from the outset with explicit citizen science objectives.

Most NCCS were affiliated with NGOs, conservation organizations, or scientific institutions, except for the Arthropods NCCS project, which was initiated privately in 2016 and without formal organizational backing; nowadays, it is connected to the NGO Közösen a Természetért Alapítvány – Together for Nature Foundation. Two projects (WildWatcher and MyPond) target both plant and animal species. WildWatcher focuses on 21 carefully selected protected species, while MyPond aims to assess the biodiversity of garden ponds, involving participants in species identification surveys and encouraging the use of a mobile app for amphibian and reptile identification. MyPond also collects data on birds and plants observed in and around ponds. The remaining projects, BeaverMap, Mosquito Surveillance Project, Butterfly-Net, Arthropods, Amphibian and Reptile Mapping Project, and the Common Bird Monitoring Program, each focus on a specific order, species, or family.

In terms of project duration, the longest-running NCCS initiative in Hungary is the Common Bird Monitoring Program (MMM), established in 1998 by MME BirdLife Hungary. This nationwide, long-term program monitors population trends of common breeding and wintering birds through standardized point counts in randomly selected locations. The extensive databases collected over the years have supported scientific research, informed conservation management, and contributed to annual reports, highlighting notable population declines in some bird species. Currently, seven NCCS projects are ongoing, while one (Butterfly-Net) has concluded. Within the scope of our analysis, BeaverMap and MyPond, both launched in 2021, are the most recent projects evaluated, and although several years have passed since their inception, they remain the latest additions among the Hungarian NCCS initiatives included in this study.

Participation requirements differ across the Hungarian NCCS projects. The Common Bird Monitoring Program (MMM) requires volunteers to have some prior knowledge of bird identification, as participants conduct structured bird counts twice a year and submit data via website or post, with expert validation and feedback provided. MyPond and Butterfly-Net target specific participant groups: MyPond engages garden pond owners in Budapest, while Butterfly-Net involves trained secondary school students from Vas County. In contrast, WildWatcher is open to the general public without requiring prior expertise, as the project specifically targets easily identifiable plant and animal species to facilitate accurate data collection and improve data quality. Similarly, the Amphibian and Reptile Mapping Project, which focuses on herpetofauna that can sometimes be challenging to identify, does not require previous expertise from participants; instead, it offers support for species identification through expert consultation and social media interaction. The remaining projects are also open to anyone nationwide, regardless of background knowledge. Across all initiatives, both the number of participants and the volume of observations have steadily increased over the years for all projects.

Table 6. Characteristics of evaluated NCCS projects in Hungary

Project Name (Hungarian)	**Purpose**	**Affiliated Institution**	**Focus Species/Group**	**Duration**	**Coverage**	**Participants' activities**	**Target Participants**	**Observations / Participants (until 2022)**
Common Bird Monitoring Program (Mindennapi Madaraink Monitoringja)	Monitor bird populations and promote conservation attitudes among the public.	MME BirdLife Hungary	Birds	1998-present	Nationwide	Biannual surveys at fixed random sites: observing, recording, identifying birds, completing questionnaires, submitting data and field notes by mail.	Public with bird identification skills	10,829 / 10,712
WildWatcher (Vadonleső)	Gather data on pre-selected protected plant and animal species that are easy to identify; enhance public awareness and environmental education.	Herman Ottó Institute NGO Ltd - Vadonleső Group	Selected easily identifiable protected plants and animals	2009-present	Nationwide	Observing, identifying, recording data online or via app, and completing questionnaires.	General public	13,830 / NI*
Amphibian and Reptile Mapping Project (Herptérkép)	Document the distribution of amphibians and reptiles for conservation.	MME BirdLife Hungary Amphibian/ Reptile Protection Dept.	Amphibians, reptiles	2011-present	Nationwide	Observing, identifying, online/app data entry, and optional photography.	General public	69,000 / 23,000
Arthropods (Ízeltlábúak)	Increase public knowledge of arthropods, update species data for science and conservation.	Private initially and since 2023 connected to the NGO (Közösen a Természetért Alapítvány – Together for Nature Foundation)	Arthropods	2016 - present	Nationwide	Observing, identifying, data entry online, photography.	General public, experts (for data validation)	321,326 / NI*

Project Name (Hungarian)	Purpose	Affiliated Institution	Focus Species/Group	Duration	Coverage	Participants' activities	Target Participants	Observations / Participants (until 2022)
Butterfly-net (Lepke-háló)	Monitor butterflies and involve youth in conservation.	Őrség National Park Directorate	Butterflies	2017–2019	Vas County	Training, observing, identifying, online data entry, and photography.	Students	NI* / 24
Mosquito Surveillance (Szúnyog-monitor)	Track the distribution of invasive mosquitoes and support control protection strategies.	HUN-REN Centre for Ecological Research	Invasive mosquitoes	2019 – present	Nationwide	Observing, collecting samples, completing surveys, submitting specimens by mail, and sending photos via email or app.	General public	3,436 / NI*
BeaverMap (HódTérkép)	Update beaver distribution, study landscape changes and human-wildlife interactions, and inform management of beaver protection of beaver-made wetlands.	HUN-REN Centre for Ecological Research	Eurasian beaver	2021-present	Nationwide	Observing, identifying, online data entry, questionnaires, and photography.	General public	350 / 500
MyPond (Az én kistavam)	Map the biodiversity of urban and garden ponds; raise awareness of urban aquatic habitats.	HUN-REN Centre for Ecological Research	Pond biodiversity	Phase 1: 2021–present; Phase 2: closed	Budapest	Surveys, observing, using sampling kits, data entry, and submitting water samples.	Garden pond owners	NI* / 342 (Phase 1), 278 (Phase 2)

NI* indicates that no data were received from project managers during the interviews.

4.1.2. Overall performance of evaluated NCCS projects

The following results are derived from a comprehensive evaluation of each project, using the three-dimensional framework criteria organized into the dimensions of science, nature conservation, and participants' development (see results in Table 7). This assessment highlights how each project performed across dimensions; therefore, according to the key components and criteria per dimension.

Table 7. Performance of NCCS projects per dimension

Dimension	Components	Criteria of the assessment	Question	Common Bird Monitoring Program	WildWatcher	Amphibian and Reptile Mapping	Arthropods	Butterfly-Net	Mosquito Surveillance	BeaverMap	My Pond
Science	Methodology	Research question	Was a scientific question formulated before starting the project?	1	0	0	0	0	1	1	1
		Methodology for data collection	When recording an observation, is supporting information (e.g., a photograph, videos) mandatory to upload as part of the data collection methodology?	1	0	0	1	1	1	1	1
		Technology use	Does the project require the use of technology that supports data collection and data quality? (e.g., smartphones, tablets, sensors)	1	1	1	1	1	1	1	1
	Data Quality	Data validation	Are protocols for data collection tested and validated before starting the project, in order to ensure data quality?	1	0	0	0	1	0	0	0
			Do they have an effective strategy for data quality assessment? (e.g., specialized professionals involved, request for more information to participants, site visits)	1	1	1	1	1	1	1	1
		Institutional affiliation	Is the project formally connected to a larger scientific or conservation organization?	1	1	1	1	1	1	1	1

Dimension	Components	Criteria of the assessment	Question	NCCS Projects							
				Common Bird Monitoring Program	WildWatcher	Amphibian and Reptile Mapping	Arthropods	Butterfly-Net	Mosquito Surveillance	BeaverMap	My Pond
	Data management practices	Long-term databases	Does the project have long-term databases?	1	1	1	1	0	1	1	1
	Data management practices	Open data	Is there any summary of the data collected released to the public? (e.g., summaries in the form of maps, charts, statistics)	1	1	1	1	0	1	0	1
	Data management practices	Open data	Are data stored in suitable repositories? (e.g., the General Data Protection Regulation [GDPR] considered)	1	1	1	1	1	1	1	1
	Data management practices	Open data	Are complete or partial databases publicly available for download?	0	0	0	1	0	0	0	0
	Data management practices	Publications	Have the findings/data been published in peer-reviewed academic journals? (For example, has the collected data been used in scientific publications or cited in academic journals or scientific books?)	1	1	1	1	1	1	1	1
Nature Conservation	Environmental monitoring	Data use in species/ ecosystem monitoring	Has the data collected by volunteers through the project been used for species or ecosystem monitoring?	1	1	1	1	1	1	1	1
Nature Conservation	Environmental management	Data use in species/ ecosystem management	Has the data collected by volunteers through the project been used for species or ecosystem management?	1	1	1	1	1	0	0	0
Nature Conservation	Policy	Data use in conservation policymaking	Has the data collected through the project influenced policy decisions at the local, national, regional, or European Union level?	1	1	1	0	0	0	0	0

Dimension	Components	Criteria of the assessment	Question	Common Bird Monitoring Program	WildWatcher	Amphibian and Reptile Mapping	Arthropods	Butterfly-Net	Mosquito Surveillance	BeaverMap	My Pond
Participants' development	Training	Forms of training provided	Is personal training provided to the participants?	0	0	0	0	1	0	0	0
			Is any other form of training/knowledge transfer provided to the participants? (e.g., written guidelines, videos, an informative phone application, or a website)	1	1	1	0	1	1	1	1
	Additional learning support	Educational events	Are events to support learning and promote environmental education organized?	1	1	1	0	1	0	1	1
		Communication for gaining knowledge	Are there ways to connect with available experts who can answer participant questions and resolve issues? (e.g., via email, social media, app chat)	1	1	1	0	1	1	1	1
	Measurement strategies for participants personal development	Measurement of knowledge gained/ reinforced	Is the participants' knowledge assessed? (e.g., species recognition, knowledge about the species ecology, conservation knowledge)	0	1	1	0	1	0	0	0
		Measurement of skills - gained/ reinforced	Are participants' skills assessed? (e.g., using equipment, data collection protocol)	0	0	0	0	1	0	0	0
		Measurement of attitude/ behavioral change	Are participants' attitudes/behavior assessed?	0	1	1	0	0	0	0	0
		Strategies for reinforcing and increasing knowledge through feedback	Do participants receive feedback that reinforces their knowledge, such as in-person, email, or app-based responses?	1	0	1	1	1	1	0	1
				17	15	16	12	16	13	12	14

The comparative analysis of the eight NCCS projects reveals notable differences in performance across the three dimensions. In the science dimension, the Common Bird Monitoring Program achieved the highest score at 100 points, with Mosquito Surveillance and MyPond also performing well, each reaching 90 points. In the nature conservation dimension, the Common Bird Monitoring Program, Amphibian and Reptile Mapping, and WildWatcher all reached the highest possible points (100 points). Conversely, projects such as Mosquito Surveillance, BeaverMap, and MyPond scored lower in this area, each with 33 points. Participants' development dimension showed greater variation across projects. Butterfly-Net led this dimension with a perfect normalized score of 100 points, highlighting its significant engagement and development impact on participants. Amphibian and Reptile Mapping and WildWatcher also scored strongly, achieving normalized scores of 86 points and 71 points, respectively. In contrast, Arthropods scored lowest at 14 points, suggesting minimal performance in this dimension relative to other projects (see Table 8).

Table 8. Summary of composite normalized score results for evaluated NCCS projects in Hungary

	Science (points)	**Nature Conservation (points)**	**Participants' development (points)**	**Total**
Common Bird Monitoring Program	100	100	57	**257**
WildWatcher	70	100	71	**241**
Amphibian and Reptile Mapping	70	100	86	**256**
Arthropods	90	67	14	**171**
Butterfly-Net	70	67	100	**237**
Mosquito Surveillance	90	33	43	**166**
BeaverMap	80	33	43	**156**
My Pond	90	33	57	**180**
TOTAL	**660**	**533**	**471**	

When analysing the total scores based on the maximum achievable points per project (300 points), the following performance profiles were found:

- The Common Bird Monitoring Program leads with the highest total score (257/300 points), showing exemplary performance in both scientific contribution and conservation outcomes, though with moderate participant development. This indicates a well-established project that excels in generating valuable, policy-relevant data and influencing conservation practices.
- Amphibian and Reptile Mapping (256/300 points) and WildWatcher (241/300 points) projects followed the next best performers. Both exhibit strong integration of CS data into nature conservation outcomes, with Amphibian and Reptile Mapping notably excelling in participant development (86/300 points), indicating effective volunteer engagement and education.

- The Butterfly-Net project achieves a high participant development score (100/300 points) and solid overall performance (237/300 points), suggesting a strong focus on participants' development and outreach alongside moderate nature conservation and scientific performance.

Lower total scores for projects like Arthropods (171/300 points), Mosquito Surveillance (166/300 points), BeaverMap (156/300 points), and My Pond (180/300 points) reflect uneven performance (often strong in scientific data collection but weaker in nature conservation or participants' development). For example, Arthropods scored well in the science dimension but had very low performance in the participants' development dimension, indicating potential areas to enhance volunteer engagement or educational support. Similarly, Mosquito Surveillance and BeaverMap exhibited limited performance in nature conservation and participants' development.

These results suggest that while many projects effectively contribute to scientific knowledge, integrating data into conservation management and fostering participant growth are key areas where projects vary considerably.

Based on the total scores for each dimension across all projects (with a maximum possible score of 800 points per dimension), the results are as follows:

- Science: the projects collectively scored 660 points out of 800, indicating strong achievement in meeting science-related criteria.
- Nature conservation: the total score is 533 points, showing moderate success in fulfilling nature conservation outcomes.
- Participants' development: the projects produced 471 points, which is the lowest among the three dimensions, suggesting more room for improvement in participant engagement and development.

The next sections present a detailed breakdown of project performance across the three dimensions—Science, Nature conservation, and Participants' development, analysing results by specific criteria within each dimension. This disaggregated approach highlights the strengths and weaknesses of individual projects, with a particular focus on their scientific contributions within the NCCS evaluation framework.

4.1.3. Scientific contribution of the evaluated NCCS projects

The comparison of scores across the eight Hungarian NCCS projects shows that the science dimension was consistently the strongest. All projects scored above 60 points, with several exceeding 80 points. Notably, the Common Bird Monitoring Program scored 100 points, and Mosquito Surveillance, My Pond, and Arthropods reached 90 points (Table 8).

Science-related criteria such as the use of technology, data validation performed by experts and institutional affiliation were consistently strong across all projects. However, differences emerged in areas like data validation and open data practices. Only a few projects (e.g., Common Bird Monitoring Program, Butterfly-Net, Arthropods) validated data collection protocols before launch, though all employed quality assessment strategies during implementation. While most projects maintained long-term databases, only Arthropods provided publicly downloadable data.

Overall, the selected NCCS projects reflect a shared commitment to scientific rigor and structured collaboration, though improvements in data validation and openness are still needed. The following section presents detailed results for each assessment criterion within the science dimension.

Methodology

Several projects, including the Common Bird Monitoring Program, Mosquito Monitor, BeaverMap, and MyPond, developed a clear scientific question prior to project initiation, ensuring focused research objectives. Methodologies for data collection varied: for example, the Common Bird Monitoring Program employed a randomized sampling design adapted from the UK Breeding Bird Survey. While some projects required supporting information, such as photographs for observations, in their data collection protocols, others, like WildWatcher, did not require image uploads, and Amphibian and Reptile Mapping made photo uploads optional but required GPS coordinates and questionnaire completion. Technology use was widespread, with most projects utilizing smartphones, GIS tools, and websites or phone apps to facilitate data collection, except for Butterfly-Net (Table 7).

Data management practices

All projects maintained appropriate data storage and sharing practices. Arthropods uniquely offered open access to raw data, while others shared validated data summaries via online platforms, including interactive maps and graphs. Projects carefully managed sensitive data, such as locations of endangered species and participants' personal information. For example, BeaverMap restricted sharing of beaver dam locations until legal protections were in place. Older projects published scientific papers to disseminate findings, while newer projects planned publications. The Arthropods data were widely used by external researchers for scientific purposes and theses.

Scientific output use

The outcomes of Hungarian NCCS projects demonstrated scientific robustness, as evidenced by the integration of their data into scientific publications, atlases, and annual reports (Sillero et al., 2014; Kóbor, 2021; Szép & Gibbons, 2000). Among these, the Arthropods project stood out as the initiative whose data were used most extensively in scientific research, with numerous external studies and publications drawing on its databases. Results from the Common Bird Monitoring Program (MMM) and Amphibian and Reptile Mapping also contributed to peer-reviewed research and informed conservation management and policy, such as the designation of a protected zone in Budapest based on fire salamander data from Amphibian and Reptile Mapping observations. The fact that the outcomes of several national NCCS projects were regularly incorporated into new scientific research highlighted their credibility and reliability. This ongoing dissemination of results through publications across all projects was a positive driver for advancing the field, showing that, step by step, NCCS initiatives in Hungary effectively addressed challenges related to data credibility and established themselves as valuable contributors to scientific conservation science.

Protocol testing

Protocol testing or pilot studies played a crucial role in establishing reliable data collection procedures in several Hungarian NCCS projects. For example, before the official launch of the Common Bird Monitoring Program (MMM), the organizers developed and tested a detailed methodology modelled after the UK Breeding Bird Survey. This process included creating structured protocols for participants' training, field data collection, and data submission, ensuring that volunteers could consistently gather high-quality information. Similarly, the Butterfly-net project conducted pilot testing with secondary school students to evaluate and refine its data collection protocol. This preparatory phase allowed the project team to assess participants' understanding of butterfly identification and monitoring techniques and to make necessary adjustments before full-scale implementation. These pilot efforts not only minimized errors but also provided participants with clear guidance, ultimately strengthening the scientific robustness of the data collected in both projects.

Data validation

The eight Hungarian NCCS projects employed a range of strategies to ensure data quality, typically centred on expert validation and, in some cases, additional verification steps. The Common Bird

Monitoring Program (MMM) demonstrated a robust approach: after participants submitted bird count data through online and postal channels, two bird experts systematically reviewed all records. When inconsistencies arose, experts contacted participants via email for clarification, and every contributor received feedback on their submissions. This multi-layered process not only upheld data accuracy but also fostered participants' learning and engagement.

In the Amphibian and Reptile Mapping project, seven herpetofauna experts were responsible for validating incoming observations. If uncertainties or inconsistencies were detected, experts reached out to participants for further information. Observations that could not be verified were excluded from the main database, ensuring that only validated records were used for scientific and conservation purposes. Direct communication channels, such as email and Facebook groups, facilitated this expert-participant interaction, and the project also leveraged educational apps and resources to support accurate data submission.

WildWatcher assigned a dedicated expert to each species for validation. While uploading photos was not mandatory, experts occasionally conducted field verification, particularly when plant data inconsistencies were noted. Their approach of targeting easily recognizable species was adopted as a strategy for ensuring data quality for participants' observations. This targeted approach allowed for flexible yet rigorous quality control, and validated records were integrated into the main database, which was then used for scientific reporting.

The Arthropods project relied on a network of volunteer taxonomists, who registered for identification roles before they could validate records. Photos were mandatory for each submission, and only after expert review did a record become part of the validated database. This peer-review-like process, while effective, could be slowed by the availability of qualified volunteers, but it ensured that only high-confidence identifications were included in the official database.

Other projects, such as BeaverMap and Mosquito Monitoring, also implemented expert review of submitted photos and records. In cases where images were unclear or data were incomplete, biologists requested additional information from participants before validation. This iterative process helped maintain data reliability, even as these projects were still in the early stages of data use.

Across all projects, the use of digital platforms, apps, and direct communication with experts enhanced the efficiency and transparency of data validation. While resource-intensive methods like site visits were rare, the combination of expert oversight, participants' feedback, and, in some cases, peer verification collectively supported a high standard of data quality assessment in Hungarian NCCS initiatives.

4.1.4. Nature conservation role of evaluated NCCS projects

The evaluation of eight Hungarian NCCS projects revealed that all initiatives made meaningful contributions to nature conservation, particularly in data collection, monitoring and management of protected species (Amphibian and Reptile Mapping, WildWatcher, BeaverMap) and invasive species (Mosquito Monitoring Project). According to the nature conservation dimension scores, the Common Bird Monitoring Program, WildWatcher, and Amphibian and Reptile Mapping achieved the highest scores (100 points) as seen in Table 8, reflecting their significant and longstanding contributions to biodiversity monitoring and habitat protection. The performance of the NCCS projects within the nature conservation dimension is presented below, following the specific criteria of the assessment framework.

Data use in species/ecosystem monitoring

All eight Hungarian NCCS projects contributed data for species or ecosystem monitoring. For example, the Common Bird Monitoring Program and Amphibian and Reptile Mapping provided long-term databases on bird and herpetofauna populations, respectively. MyPond collected biodiversity data on garden ponds, while Mosquito Monitor tracked the distribution of invasive mosquito species. These monitoring activities enabled comprehensive tracking of species presence, abundance, and distribution across Hungary.

Notably, the Arthropods project follows the practice of allowing open access to its data, which has led to significant usage and downloads. This openness has contributed to notable discoveries of new species occurrences in Hungary, such as *A. heegeri* (Károlyi & Rédei, 2017), *Cybocephalus nipponicus* (Merkl et al., 2017), and the detection of invasive species like *Acanalonia conica* (Kóbor, 2021) and *Halyomorpha halys* (Vétek et al., 2018).

Data use in species/ecosystem management

For the environmental management component, several projects demonstrated that their data were used to inform direct management actions. In the Mosquito Monitor project, participants collected invasive mosquito specimens, aiding efforts to control these species, which are both conservation concerns and vectors for diseases affecting human health. WildWatcher reports on hedgehog (*Erinaceus roumanicus*) sightings outside their typical range prompted habitat management interventions. Amphibian and Reptile Mapping data supported the protection of fire salamander

(*Salamandra salamandra*) habitats in Budapest, while Butterfly-Net student observations led to the discovery of a new butterfly population, resulting in habitat protection measures by the Őrség National Park Directorate.

Data use in conservation policy making

Older projects, in particular, performed strongly in this area. WildWatcher data have been incorporated into the Hungarian Nature Conservation Information System (TIR) and contributed to Hungary's national reporting under Article 17 of the EU Habitats Directive. Butterfly-Net data were added to the OpenBioMaps biodiversity platform (Bán et al., 2022), making them accessible to decision-makers for biodiversity management. Amphibian and Reptile Mapping regularly supplies data to the European Atlas of Amphibians and Reptiles (SEH, NA2RE) (Sillero et al., 2014) and for EU reporting. The Common Bird Monitoring Program provides the largest ornithological database in Hungary, supporting both EU-wide bird monitoring and the national annual bird atlas (Szép et al., 2021).

4.1.5. Impact of evaluated NCCS projects on participants' development

The participants' development dimension showed the greatest variation among the eight Hungarian NCCS projects. The highest scores were achieved by Butterfly-Net (100 points), Amphibian and Reptile Mapping (86 points), and WildWatcher (71 points), indicating relatively strong support for participants' learning and development in these initiatives. In contrast, Arthropods scored notably lower at 14 points, while Mosquito Surveillance and BeaverMap each attained 43%, and both the Common Bird Monitoring Program and My Pond registered 57 points (see Table 8). The next section presents the results of the more detailed analysis of participants' development dimension, drawing on questionnaires responses from participants in the Amphibian and Reptile Mapping and WildWatcher projects. The results per the criteria of the participants' development dimension are as follows:

Training provided

Butterfly-Net stood out as the only NCCS project to combine in-person training (such as lectures on butterfly biology and identification) with supplementary resources, including field guides, mobile apps, and environmental education events. Other projects primarily relied on online materials available through their websites, where participants could access detailed instructions for fieldwork, data collection protocols, and species identification. The Common Bird Monitoring Program, for instance, provided additional resources like bird sound guides, maps, and field diaries. MyPond offered training through instructional videos and sampling kits, which included conservation-focused guides, sampling tools for water chemistry and eDNA, data sheets, and user manuals. Similarly, Mosquito Monitor produced videos to show mosquito trapping techniques.

Additional learning support

This component examined educational tools or events, and communication channels that support participants' learning. Several projects hosted events, such as "Mammal of the Year" (WildWatcher) and "Amphibian and Reptile of the Year" (Amphibian and Reptile Mapping), to promote environmental education and conservation awareness, often advertised via social media. The Common Bird Monitoring Program organized recognition gatherings where observers could receive awards and share experiences, fostering a sense of community. Many projects provided direct access to experts for participant questions or concerns. For example, BeaverMap volunteers, mainly farmers, frequently consulted experts about beaver-related issues. Participants in Amphibian and Reptile Mapping and WildWatcher also used social media platforms (e.g., Facebook) to communicate with both experts and peers, sharing photos and seeking advice on species identification. These interactions not only reinforced knowledge but also helped ensure accurate species recognition before data submission.

Measurement of personal development

The final component considered how projects assessed participants' knowledge, skills, attitudes, and behaviours. While all eight initiatives contributed to increasing knowledge about species in Hungary, none formally evaluated the knowledge or skills gained by participants after their involvement at the time of the interviews. Similarly, there were no formal assessments of changes in attitudes or behaviours. In the case of MyPond, coordinators noted that, although no survey was conducted, participants' willingness to proceed to the second phase (using the kit box for measurements) indicated a positive attitude toward continued engagement. Six projects (the Common Bird Monitoring Program, Amphibian and Reptile Mapping, Butterfly-Net, Arthropods, Mosquito Monitor, and MyPond) offered some form of feedback, such as emails or app notifications, to reinforce participant learning. Although coordinators believed that providing feedback encouraged ongoing participation, there was no formal evaluation of its impact on volunteers or project outcomes.

4.1.6. Discussion of the results of the evaluated NCCS projects

The results of the initial overview of the analysed Hungarian NCCS projects demonstrate strong achievements in both scientific output and contributions to nature conservation. However, our evaluation also reveals substantial opportunities for further improvement in the participants' development dimension outcomes. This pattern closely aligns with the findings of Peter et al. (2021), who, in their assessment of NCCS projects, observed that while these programs are highly effective at generating scientific data and supporting conservation goals, their influence on participants' learning, behavioural change, and wider educational benefits is often inconsistent and not systematically assessed. Their earlier research (Peter et al., 2019) similarly highlighted that, although CS holds significant promise for advancing nature conservation, actual improvements in participants' knowledge, attitudes, or behaviours tend to vary and are frequently under-evaluated.

The outcomes of this research from the science dimension highlight the critical role that high data quality standards play in establishing NCCS projects as valuable contributors to scientific research, a point emphasized by Wiggins et al. (2013). Internationally, projects such as eBird illustrate how rigorous protocols and robust validation processes can lead to significant scientific achievements, including a large number of peer-reviewed publications (Bonney et al., 2014; Sullivan et al., 2014; Kelling, 2018). Within Hungary, the Common Bird Monitoring Program stands as a leading example, having adopted the UK's Breeding Bird Survey methodology and consistently upholding strict standards for data collection and verification. This dedication has enabled the program to build one of Hungary's most extensive and reliable ornithological databases.

A key factor supporting these high standards is the strong institutional backing observed across the evaluated projects, as institutional support and collaboration with scientific organizations are widely recognized as essential for ensuring data quality and project sustainability in citizen science (Downs et al., 2021; US Environmental Protection Agency (EPA), 2019). Even projects that initially operated independently, such as Arthropods, have since sought organizational partnerships, highlighting a growing recognition of the importance of institutional support for data quality and project sustainability.

Open data practices further influence the scientific reach and impact of citizen science. As noted by Turbé et al. (2020), projects that make their databases openly available tend to produce more scientific outputs and foster wider data use. In the Hungarian context, only the Arthropods project has fully embraced open access, resulting in a large, widely used database. While other projects are beginning to publish their findings (such as Mosquito Monitor and MyPond) (Garamszegi et al., 2023; Márton et al., 2023), there remains significant potential to improve data accessibility and sharing across the NCCS field and scientific community. Similar trends have been reported in other European countries' assessments; for instance, Von Gönner et al. (2023) found that while data quality assurance is common, open data practices and widespread publication are still developing in Germany, Austria, and Switzerland.

From the nature conservation dimension, our findings confirm that selected Hungarian NCCS projects make valuable contributions to species and ecosystem monitoring, as well as to practical management and conservation actions. All evaluated projects supported monitoring activities, with several also informing habitat protection, invasive species management, and human-wildlife conflict mitigation. Projects with longer operational histories (such as Amphibian and Reptile Mapping, WildWatcher, and the Common Bird Monitoring Program) were particularly strong in this area, reflecting their established roles in environmental management and, to a lesser extent, policy influence. This is consistent with broader research indicating that citizen science data are often most impactful in habitat and population management, rather than direct policy or legislative action, when there are long-term datasets available (Sullivan et al., 2014; Chandler et al., 2017; McKinley et al., 2017; Turbé et al., 2020).

Our results indicate that NCCS projects with the longest temporal scope (such as Amphibian and Reptile Mapping, WildWatcher, and the Common Bird Monitoring Program) achieved the highest scores in the nature conservation dimension, reflecting their substantial roles in environmental management and, to some extent, policy influence. However, at the time of data collection, most projects had not yet seen their data directly used in policy-making or conservation management a pattern that echoes findings from Sullivan et al. (2017), who reported that NCCS data like those from eBird were more frequently applied to habitat management and protection than to formal policy or legislative processes. Since our evaluation, several additional Hungarian projects have begun to demonstrate tangible conservation outcomes, signaling rapid growth in the field (Finger et al., 2023). Notably, one of the last to be launched of all projects, BeaverMap, has already contributed to the management of beaver-created wetlands and the resolution of human-wildlife conflicts, while ongoing data collection continues to identify high-conservation-value habitats and is expected to further refine national beaver distribution maps in the future (Juhász & Biró, 2024). These developments suggest that, with continued emphasis on data sharing, institutional collaboration, and the translation of NCCS data into practical conservation actions, Hungarian NCCS projects are well-positioned to expand their scientific and conservation impact in the years ahead.

Successful NCCS projects not only advance its scientific and conservation objectives but also provide meaningful benefits to its participants (knowledge, skills gain, attitude, and behaviour impact), as emphasized in the literature (Kieslinger et al., 2017; Hansen & Bonney, 2022). Our findings illustrate that Butterfly-Net excelled in the participants’ development dimension, largely due to its small scale, which made it feasible to offer in-person training and frequent expert interaction. These personalized learning opportunities are widely recognized in the literature as highly effective for enhancing participants' engagement and knowledge (Evans et al., 2005; Phillips et al., 2018). However, such approaches are often impractical for larger projects, which must instead rely on self-guided resources like digital tutorials, printed materials, and mobile applications to support their growing volunteer communities. Bonney et al. (2009) note that these supplementary tools can still foster confidence and skill acquisition among participants, even in the absence of direct training. Despite the recognized importance of participant outcomes, our evaluation, echoing international trends (Leonard et al., 2023), revealed that systematic assessment of changes in knowledge, attitudes, or behaviours remains rare in Hungarian NCCS projects. This gap highlights a missed opportunity, as collecting demographic and outcome data could provide valuable insights into the broader educational and social impacts of NCCS. Strengthening evaluation protocols to better capture participants' development would not only enrich our understanding of project effectiveness but also help tailor future initiatives to maximize benefits for both science and society.

4.2. Results of the comparative analysis of observation data of two Hungarian NCCS projects

4.2.1. Overview of the two selected NCCS projects' observation databases

The Amphibian and Reptile Mapping (ARM) database included a total of 74,415 observation records, which were submitted by the general public from the project's launch in 2011 until December 2024. This substantial database demonstrated both sustained participants' engagement and comprehensive national coverage in tracking Hungary's amphibian and reptile populations. Amphibians accounted for over 60% of all records, while reptiles comprised under 40% (Table 9).

The WildWatcher database contained 17,484 observation records collected between 2009 and December 2024. The majority of records belonged to mammals (56.6%), which accounted for over half of the database, followed by significant contributions from insects and flowering plants. Amphibians and reptiles together represented just over 10% of the total records (Table 9).

Table 9. Summary of observation records of the two databases

			Animals				Plants		
		Class	Mammal	Reptile	Amphibian	Insect	Liliopsida	Magnoliopsida	Total
Project	Amphibian and Reptile Mapping	Count	0	29233	445182	0	0	0	74415
		%	0.0	39.3	60.7	0.0	0.0	0.0	100.0
	WildWatcher	Count	9899	587	1367	3494	633	1504	17484
		%	56.6	3.4	7.8	20.0	3.6	8.6	100.0

4.2.2. The distribution of observations across species

There is a clear difference in the number and distribution of species observations between the two Hungarian NCCS initiatives, as shown in Figure 4 and Figure 5. In the Amphibian and Reptile Mapping project, the observations were distributed between 34 species; the majority of individuals were reported as "alive" (light blue bars) across all species, with only a small proportion recorded as "dead" (red bars) or "N/A" (green bars) (Figure 4). The highest observation counts were *for Pelobates fuscus, Rana dalmatina, Lacerta viridis, Bufo bufo, Pelophylax kl. Esculentus*, and *Emys orbicularis*, each exceeding 5,000 records, with *Pelobates fuscus* approaching 7,000 observations. Most species in this database had fewer than 2,000 observations, with a long list of less frequently reported taxa.

In the WildWatcher project, there were observations from 21 species; the total number of observations per species was generally lower compared to the Amphibian and Reptile Mapping project. The most frequently reported species were *Erinaceus roumanicus, Sciurus vulgaris, Talpa europaea*, and *Lucanus cervus*, each with observation counts ranging from approximately 1,500 to nearly 4,000. Other species, such as *Adonis vernalis*, *Mantis religiosa*, *Hyla arborea*, and *Salamandra salamandra*, had between 500 and 1,500 observations (Figure 5). As with the Amphibian and Reptile Mapping project, the majority of records in WildWatcher were of live individuals, with a smaller number of dead or N/A status reports.

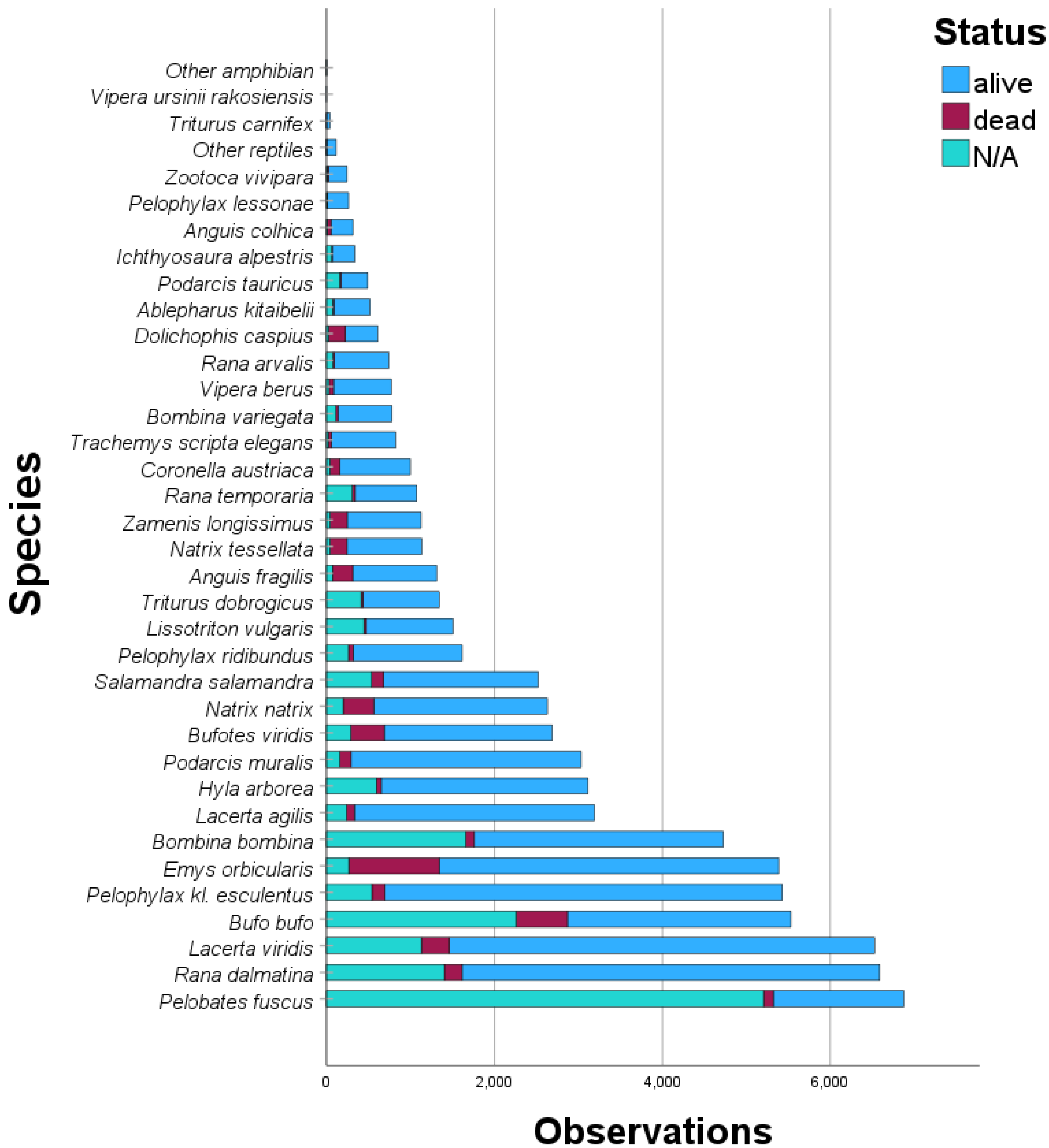

Figure 4. Distribution of species in the Amphibian and Reptile Mapping project until 2024

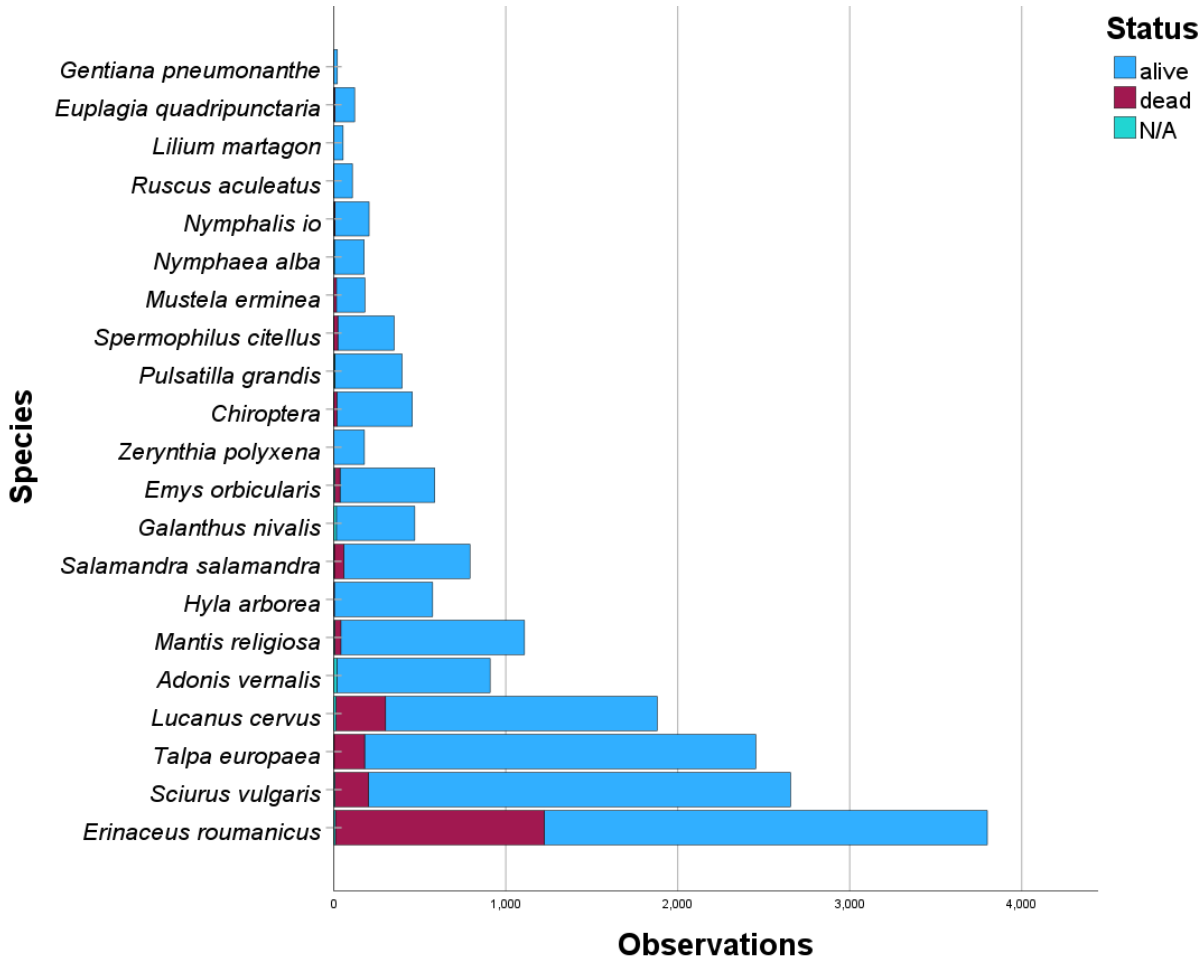

Figure 5. Distribution of species in the WildWatcher project until 2024

In terms of taxonomic classes, the Amphibian and Reptile Mapping project recorded over 45,000 amphibian observations and nearly 30,000 reptile records (Figure 6). WildWatcher demonstrated a broader taxonomic distribution, although with lower observation counts in each class. Mammals accounted for the largest share of WildWatcher's records, exceeding 10,000 observations, followed by insects and flowering plants (Magnoliopsida), each with several thousand records (Figure 6). Amphibians and reptiles were also present in the WildWatcher database, but at much lower levels compared to the Amphibian and Reptile Mapping, focusing on the herpetofauna species.

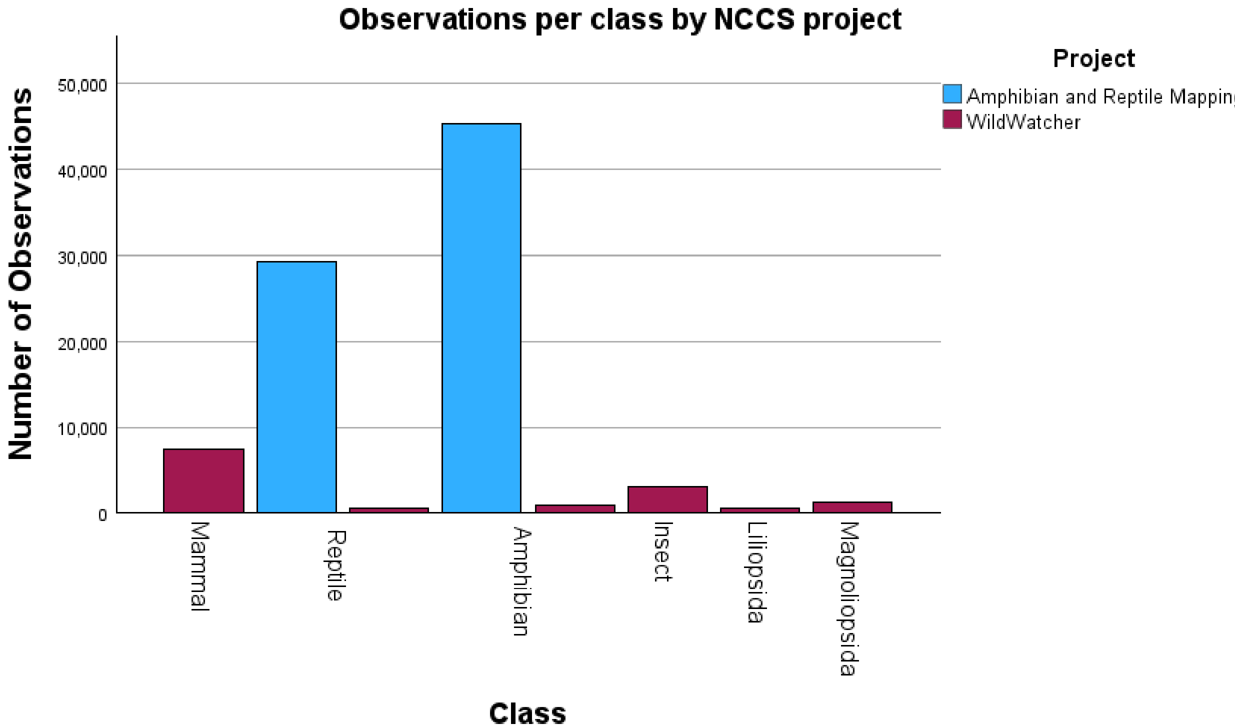

Figure 6. Distribution of taxonomic class observations in the Amphibian and Reptile Mapping and WildWatcher projects.

The Amphibian and Reptile Mapping project recorded 13 amphibian and 18 reptile species, highlighting its specialized focus on herpetofauna. WildWatcher, with its broader target species scope, recorded 2 amphibian species, 1 reptile, 5 insect species, and 6 mammals among animals, as well as 3 species of Liliopsida and 4 species of Magnoliopsida among plants (see Appendix 3, Table 17).

4.2.3. Annual trends in species observations

Figure 7 illustrates the annual trend of species observations submitted to the Amphibian and Reptile Mapping and WildWatcher projects from 2009 to 2024. Our findings show that the Amphibian and Reptile Mapping project consistently generated a much higher volume of observations per year compared to WildWatcher. Notably, Amphibian and Reptile Mapping experienced several pronounced peaks, with the most significant spike occurring in 2018, when annual observations exceeded 20,000. Other years, such as 2011 and 2016, also show substantial increases, with observation counts surpassing 10,000 and 7,000, respectively. Between these peaks, the project displayed considerable year-to-year fluctuation but generally maintained higher submission levels than WildWatcher throughout the entire period.

In contrast, the WildWatcher project maintained a relatively stable and lower rate of annual observations. Its yearly submissions typically ranged between 1,000 and 3,000, with only minor fluctuations and no dramatic peaks. This pattern suggests a consistent but more modest level of participation and data reporting for WildWatcher compared to the more variable but higher-volume participation seen in Amphibian and Reptile Mapping (Figure 7).

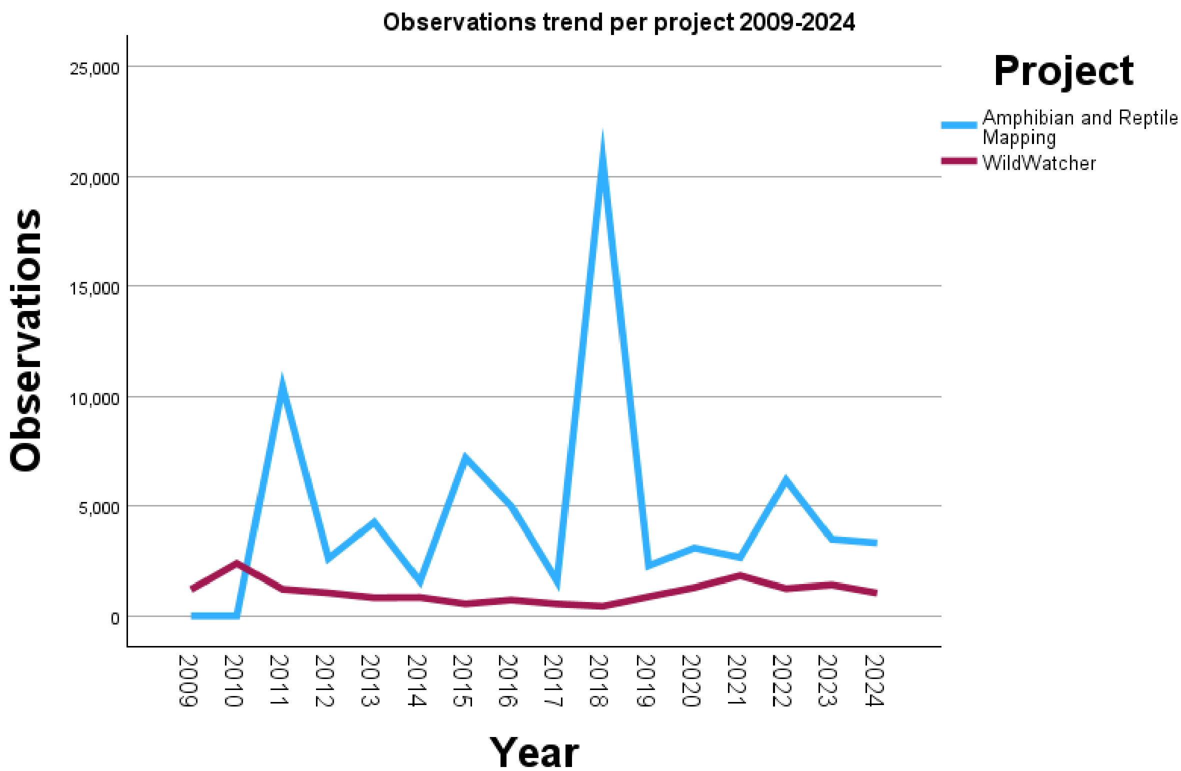

Figure 7. Annual species observations in Amphibian and Reptile Mapping (2011–2024) vs. WildWatcher (2009–2024)

Statistical analysis using the Chi-square test confirmed that the difference in the distribution of annual observation counts between the two projects is statistically significant ($p<.001$). The strength of this difference is moderate, as indicated by Cramer's $V = .318$. This result demonstrates a significant difference in observation volumes between the projects, supporting the descriptive trends observed in Figure 7.

4.2.4. Data validation status

Our results revealed that both NCCS initiatives achieved strong data quality assurance, with the vast majority of observations successfully validated. In Amphibian and Reptile Mapping, more than

70,000, representing approximately 95%, were classified as valid. Invalid records accounted for a small minority, and only a minimal number remained unchecked. WildWatcher, with 13,896 total records, showed over 12,000 validated entries, corresponding to about 90%. The proportion of unchecked records was slightly higher in WildWatcher compared to Amphibian and Reptile Mapping, while the number of invalid records remained very low in both projects (Figure 8).

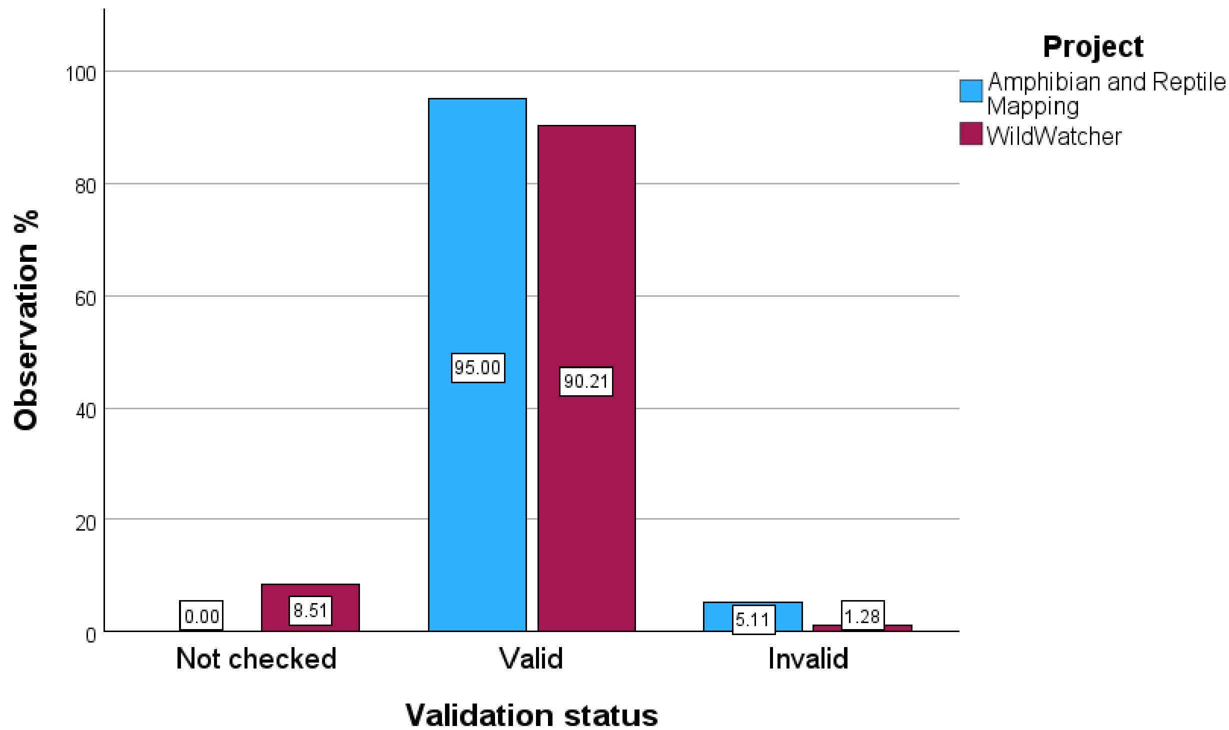

Figure 8. Data validation status between the Amphibian and Reptile Mapping and the WildWatcher projects. Note: only observations recorded between 2011 and 2024 were included to ensure that the analysis covers matching time horizons across both projects.

Annual validation patterns differed markedly between the two projects. In Amphibian and Reptile Mapping, the number of validated records fluctuated over the years, with notable peaks in 2011 (9977 records-95%) and especially 2018, when validated observations exceeded 20,000 (20422 records-98%) (Figure 9). In most years, the vast majority of records were classified as valid, with only a small fraction marked as invalid or not checked. The volume of unchecked and invalid records remained consistently low across all years, indicating a high level of data quality assurance throughout the project’s operation.

WildWatcher exhibited a steadier trend in annual validation, with the highest number of validated records occurring in 2011 (1205 records - representing 99%) and 2021 (1782 records - representing 97%), followed by moderate numbers in subsequent years. While the proportion of valid records remained high, WildWatcher had a slightly greater share of unchecked records compared to Amphibian and Reptile Mapping, particularly in more recent years. Invalid records were rare in both projects and did not show any clear temporal trend (Figure 9).

The Chi-square test also showed a statistically significant difference in the distribution of validation status (valid, invalid, unchecked) of observations between the projects ($p<.001$), with a moderate association strength (Cramer's V = .276). This indicates that validation varies significantly between the projects.

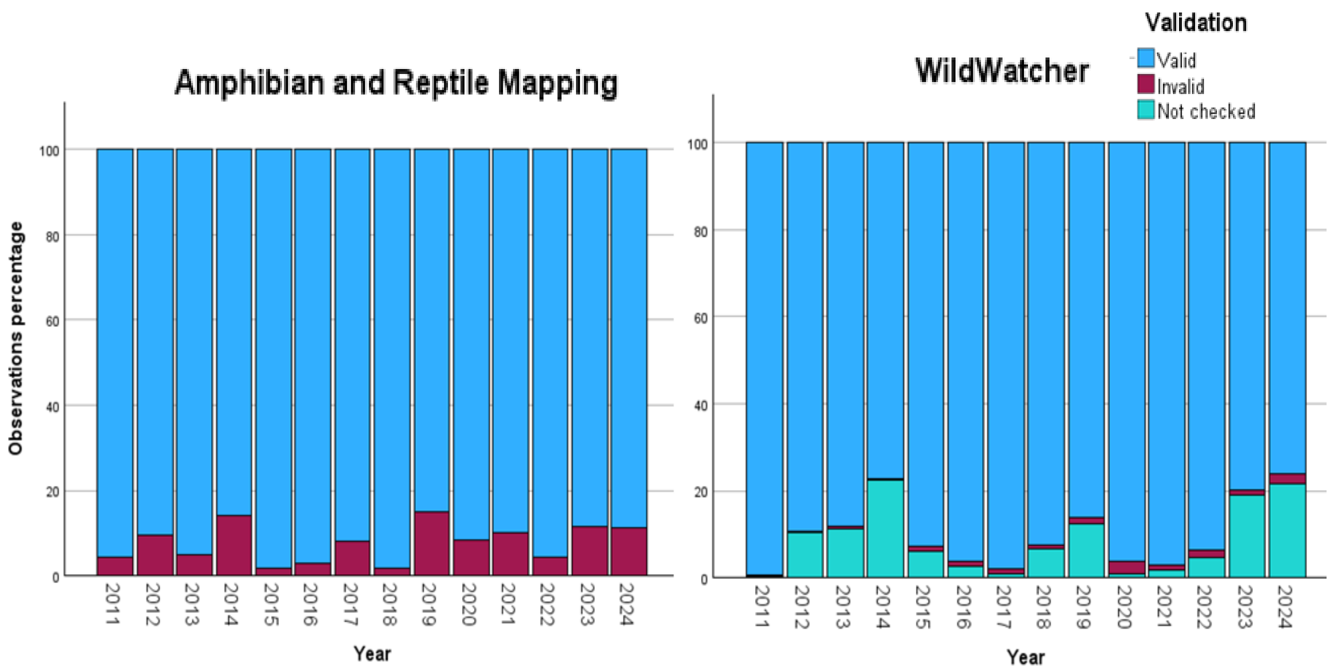

Figure 9. Annual trends in data validation status per NCCS project. Note: only observations recorded between 2011 and 2024 were included to ensure that the analysis covers matching time horizons across both projects.

Statistical analysis confirmed the differences between projects in validation status across years are significant, as indicated by the chi-square test ($p<.001$), consistently. Cramer's V values ranged from 0.088 to 0.431, indicating that the relationship between year and validation status was generally weak to moderate, but reached moderate to strong levels in certain years (e.g., 2014, 2019, 2023, and 2024). This suggests that, while the overall difference was statistically significant throughout, the practical impact of year-to-year variation in validation outcomes was more pronounced in some periods.

4.2.5. Mobile app usage

Analysis of mobile app usage to make observations across the two NCCS projects revealed marked differences in the preferred data submission interface. In the Amphibian and Reptile Mapping project, the vast majority of observations, nearly 70,000 (90%), were submitted through interfaces other than the mobile app, while approximately 7,500 (10%) records originated from the mobile application (slightly higher than WildWatcher) (Figure 10). Similarly, in the WildWatcher project, most observations, around 15,000 (81%) were recorded via non-mobile interfaces, with fewer than 3,500 (19%) submissions made using the mobile app (Figure 10).

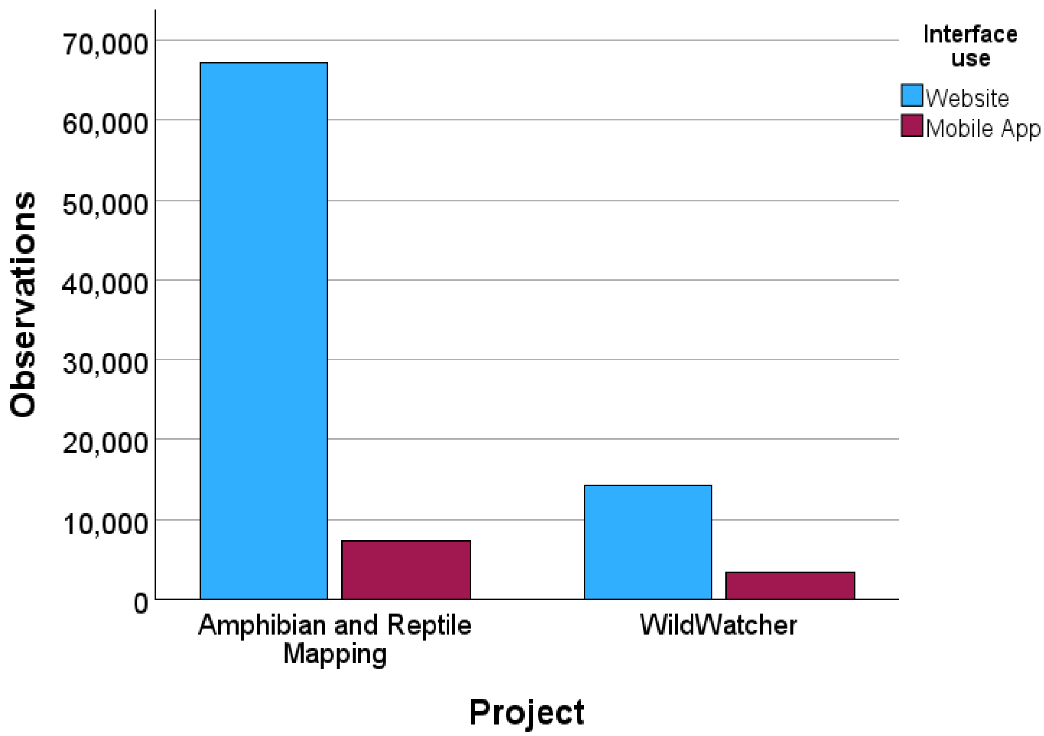

Figure 10. Mobile app usage across Amphibian and Reptile Mapping and WildWatcher. Note: only observations recorded between 2011 and 2024 were included to ensure that the analysis covers matching time horizons across both projects.

Statistical testing confirmed a difference in interface usage between the two projects as significant (Fisher's exact test $p<.001$). The strength of this association, as measured by Cramer's V value (0.150), suggests a weak but meaningful strength between project type and preferred submission interface.

4.2.6. Discussion of the results of the comparative analysis of observation data of two Hungarian NCCS projects

The focused analysis of Hungary's Amphibian and Reptile Mapping and WildWatcher NCCS projects highlights their substantial role in supporting science and nature conservation, particularly through the generation of large, validated databases that inform management and conservation strategies for a range of species.

Impact of long-term biodiversity databases

Both projects accumulated substantial databases over a decade or more, mirroring the scale and reach of leading platforms like eBird and iNaturalist, which have demonstrated the value of public participation in generating extensive, spatially and temporally rich observation data (Sullivan et al., 2009; Callaghan et al., 2020; Ackland et al., 2024). Similarly, our findings are consistent with experiences in the UK and Germany, where long-term citizen science initiatives like the UK Butterfly Monitoring Scheme have played a vital role in tracking biodiversity trends and informing conservation efforts (Chandler et al., 2017). Across all these cases, expert validation and systematic data management remain essential for ensuring that NCCS data can be translated into credible, policy-relevant outcomes for conservation (Kelling, 2018; Downs et al., 2021).

The databases have impacted conservation actions. The two analyzed NCCS projects have shown strong capacity for sustained public engagement and the generation of high-quality, validated databases. Amphibian and Reptile Mapping, with over 94% of records confirmed as valid, this project's data has directly supported conservation actions. These findings underscore the significant and expanding role of NCCS in biodiversity monitoring and conservation planning, both in Hungary and the CCE region. The conservation impacts observed (such as the use of the project's data for habitat protection, species distribution analyses, and the development of mitigation measures) are consistent with outcomes from similar European initiatives, including Austria's Herpetofauna project Red List assessments and conservation policy (Dörler & Heigl, 2019). Furthermore, the integration of rigorously validated, multi-taxa databases with rich metadata into national systems, as exemplified by WildWatcher's contribution to the Hungarian Nature Conservation Information System (TIR), reflects best practices seen in projects like Artportalen in Sweden, which is a national NCCS platform for biodiversity observations. It collects data on plants, animals, and fungi from the public and serves as a primary source of biodiversity information for Swedish authorities and governmental agencies (Sjödin Skarp, 2019). These examples collectively demonstrate that, when supported by expert validation and systematic data management, NCCS can provide high-quality data that are both scientifically valuable and directly relevant for conservation decision-making.

Seasonality and biodiversity observation trends

The pronounced annual peaks in Amphibian and Reptile Mapping (particularly in years such as 2011, 2016, and 2018) reflect not only the impact of targeted campaigns and seasonal events but also the unique biological and ecological characteristics of herpetofauna. Amphibians and reptiles are inherently cryptic, often active only during specific periods that coincide with favourable environmental conditions like optimal temperature and rainfall. These short windows of high detectability naturally concentrate both survey efforts and data submissions, resulting in marked fluctuations in annual observation numbers (Baumgardt et al., 2021).

Unlike more noticeable and easily identifiable species that dominate generalist projects such as WildWatcher or iNaturalist (Callaghan et al., 2022), herpetofauna require specialized knowledge for accurate identification and are less likely to be encountered outside their peak activity periods. This leads to a pattern where professional projects experience bursts of engagement aligned with biological cycles, while generalist projects benefit from a broader display of readily observable species, supporting steadier, year-round participation (Wittmann et al., 2019). Recognizing these differences is essential for interpreting the strengths and limitations of NCCS databases. By adapting project design and data analysis strategies to account for biological factors (such as the seasonality and detectability of target taxa), researchers and conservation practitioners can maximize data quality and reliability. Ultimately, this tailored approach not only improves the scientific value of NCCS data but also increases its credibility and applicability in conservation planning, species management, and policy-making. In this way, thoughtful integration of biological and project design considerations directly supports the effective use of NCCS data for evidence-based nature conservation actions.

4.3. Results of the comparative analysis of the participant questionnaires of the two Hungarian NCCS projects

4.3.1. Overview of respondents' characteristics

A total of 291 participants completed the online questionnaires: 185 from Amphibian and Reptile Mapping and 106 from WildWatcher (Table 10). Most respondents in both projects resided outside Budapest (75.7% and 68.9%, respectively). The majority were middle-aged (31–50 years: 55.7% for Amphibian and Reptile Mapping, 44.3% for WildWatcher), with a substantial proportion over 50 years old. Both projects attracted highly educated participants (over 69% held higher education degrees). About one-third were members of a nature conservation NGO, and a similar proportion worked or studied in nature conservation.

A significant gender difference was observed (Chi-square p = .004, Cramer's V = .168), with Amphibian and Reptile Mapping having a higher proportion of male respondents (61.2%) compared to WildWatcher (43.8%) (Table 10).

Table 10. Demographics of participants

Participant Characteristic	**Answer Option**	**Amphibian and Reptile Mapping**	**WildWatcher**	**Chi-square / Cramer's V**
		%	%	p-value
Total participants		N=185,100%	N=106,100%	
Place of residency	Outside Budapest	75.7	68.9	0.207
	Budapest	24.3	31.1	
Gender	Male	61.2	43.8	0.004* / 0.168
	Female	38.8	56.2	
	Prefer not to say **	1.1	0.9	
Age group	Under 30	13.5	17	0.177
	31-50	55.7	44.3	
	Over 50s**	30.8	38.7	
Highest level of education	Primary education **	2.2	7.5	0.393
	Secondary education	28.6	22.6	
	Higher education	69.2	69.8	
Member of a nature conservation NGO	Yes	37.3	32.1	0.37
	No	62.7	67.9	
Workplace/education related to conservation	Yes	30.8	32.1	0.686
	No	69.2	67.9	

Note: *Asterisks indicate p-values that represent statistically significant differences between the two projects (p<.05). **Categories with very few responses were excluded or merged to enable the performance of the Chi-square test.

4.3.2. Participation patterns and technology use

First encounter with the NCC project

Social media emerged as the most common first encounter source for both groups (38.4% for Amphibian and Reptile Mapping, 40.6% for WildWatcher). However, a significant difference was observed regarding traditional media: only WildWatcher participants reported television/radio or newspaper as their initial source of information minimally (2.8% each), while no participants from the Amphibian and Reptile Mapping project mentioned these sources. This difference was statistically significant (Chi-square p = .047, Cramer's V = .135), indicating that WildWatcher participants were slightly more likely to learn about the project through traditional media compared to Amphibian and Reptile Mapping participants, but the strength was weak (Table 11).

Table 11. Source of first encounter with the NCCS project

Source	**Amphibian and Reptile Mapping**	**WildWatcher**	**Chi-square / Cramer's V**	**Fisher's exact Test/Cramer's V**
	Yes	Yes	p-value	p-value
Social media	38.4%	40.6%	0.713	
TV, radio	0%	2.8%	-	0.047*/ 0.135
Newspaper	0%	2.8%	-	0.047*/ 0.135
Colleagues	8.1%	15.1%	0.063	
Friends	10.3%	14.2%	0.321	
**A nature conservation organization- WildWatcher option		21.5%		
**MME Birdlife Hungary - Amphibian and Reptile Mapping option	15.3%			
**MME KHVSZ (Amphibian and Reptile Conservation Group)- Amphibian and Reptile Mapping option	26.5%			
**MME website - Amphibian and Reptile Mapping option	17.9%			
**MME KHVSZ website - Amphibian and Reptile Mapping option	15.7%			

Note: A horizontal line (-) indicates that the expected count was less than 5, so Fisher's exact test was used. *p-values marked with an asterisk denote statistically significant differences between the two projects (p<.05). **Options exclusive to each project; therefore, no statistical test was applied.

Observation uploading patterns

Most participants had been involved for 1–5 years (58.9% Amphibian and Reptile Mapping, 52.8% WildWatcher), with no significant difference in involvement duration (Table 12). A significant difference in upload frequency was found (Chi-square $p<.001$, Cramer's V = .286): Amphibian and Reptile Mapping participants more often reported a "variable" upload pattern (51.9% vs. 35.8%), while WildWatcher had more "unknown" responses (19.8% vs. 3.2%) (Table 12).

Interface preferences

Most Amphibian and Reptile Mapping participants preferred the website (63.8%), while WildWatcher users were more likely to use the phone app or both platforms (Chi-square p = .002, Cramer's V = .208). Website usage frequency was similar, but phone app usage differed significantly (Chi-square $p<.001$, Cramer's V = .273), with 65.9% of Amphibian and Reptile Mapping participants never using the app, compared to 40.6% in WildWatcher (Table 12).

Table 12. Interfaces use patterns

Question	Options	Amphibian and Reptile Mapping	WildWatcher	Test Chi-square / Cramer's V p-value
Q2. Years of involvement	Unknown**	4.9%	4.7%	0.314
	Less than a year	5.9%	12.3%	
	1 to 5 years	58.9%	52.8%	
	6 to 10 years	25.4%	22.6%	
	more than 10 years	4.9%	7.5%	
Q3. Observation upload frequency	Unknown	3.2%	19.8%	<.001*/0.286
	Once	19.5%	19.8%	
	Variable	51.9%	35.8%	
	Yearly	20%	19.8%	
	Several times a year	5.4%	4.7%	
Q4. Changes in Observation upload frequency	Upload more often than before	14.6%	8.5%	0.097
	Upload less often than before	22.2%	28.3%	
	Frequency has not changed	56.2%	50%	
	Other	7%	13.2%	
Q6. Interface preference for uploading observations	Phone app	21.6%	35.8%	0.002*/0.208
	Website	63.8%	42.5%	
	Phone and website are equally	14.6%	21.7%	

Question	Options	Amphibian and Reptile Mapping	WildWatcher	Test Chi-square / Cramer's V p-value
Q7.1 Frequency of website use	Never	5.4%	10.4%	0.336
	Irregular	22.2%	25.5%	
	Yearly	59.5%	53.8%	
	Monthly	13%	10.4%	
Q7.2 Frequency of phone app use	Never	65.9%	40.6%	<.001*/0.273
	Irregular	7.6%	16%	
	Yearly	13%	29.2%	
	Monthly	13.5%	14.2%	

*Asterisks indicate p-values showing significant differences between the two projects (p<.05). **The order of response options was adjusted, with "unknown" moved to the first position.

Interface use experience

Participants in both projects generally reported positive experiences with the technology, as reflected by median scores of 4 or higher (agree) on all Q10 items, as seen in Figure 11. According to the Mann-Whitney U test results, there were no statistically significant differences between the projects in terms of the clarity and ease of submitting observations via the website or the mobile application, or the perceived effectiveness of receiving responses through the project interfaces (Table 13).

Table 13. Test results for interface use experience

Question	Test Mann-Whitney U Test p-value
Q10. Uploading my observations through the website is understandable and simple.	0.06
Q10.1 Uploading my observations through the phone application is understandable and simple.	0.937
Q10.3 Using the project interfaces, I received answers to my questions during participation	0.664

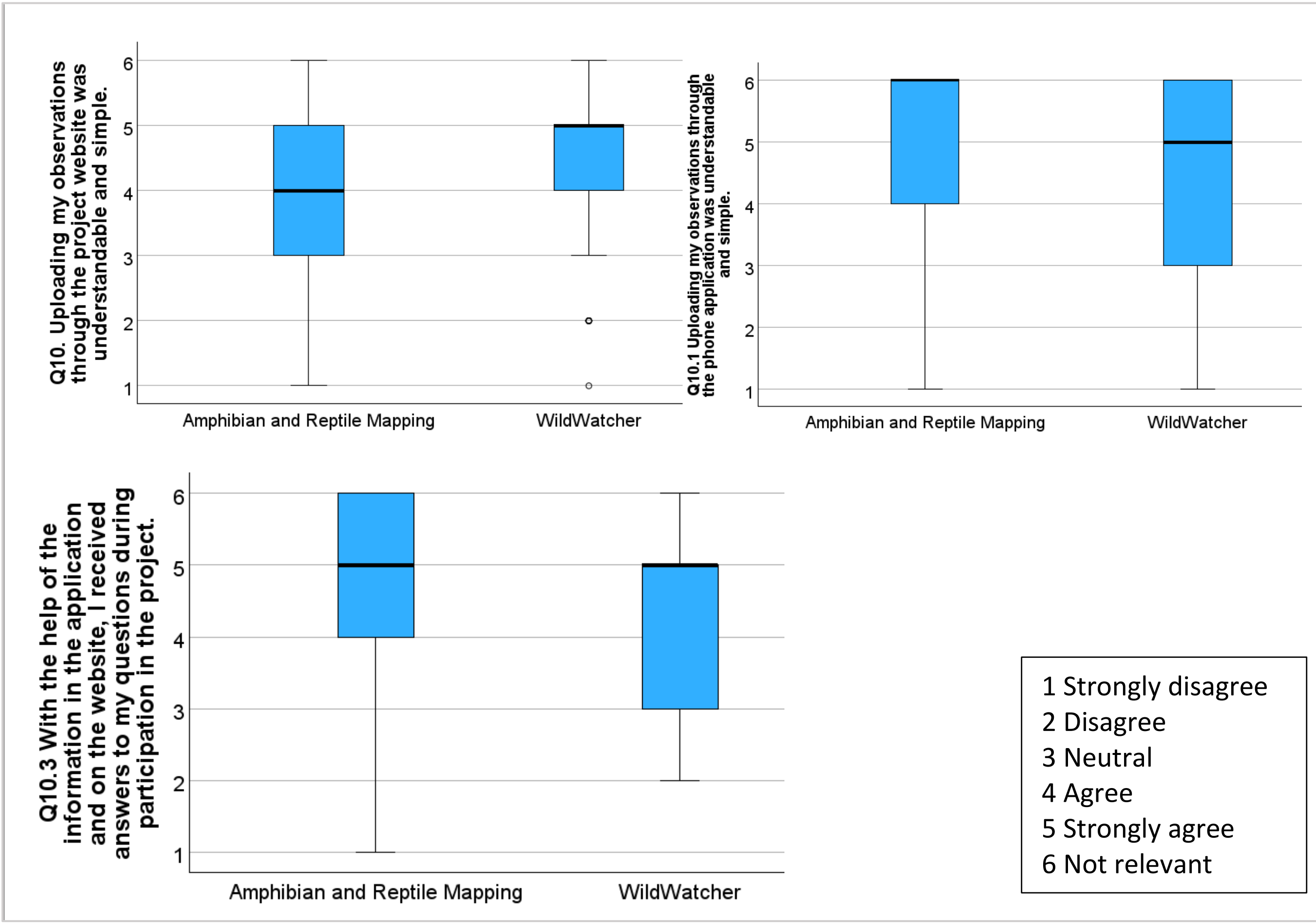

Figure 11. Interface use experience boxplot results

4.3.3. Knowledge gain

Participants' perceptions of knowledge responses for the Amphibian and Reptile Mapping and WildWatcher projects concentrated between medians 3–5 across knowledge items, with significant differences identified for some knowledge-related questions (Q18, Q18.3, Q18.6 and Q16-17):

- Knowledge from the project website (Q18). A significant difference was found between the project ($p<.001$) (Table 14). Amphibian and Reptile Mapping participants reported stronger agreement about gaining knowledge from the website (median = 4, mostly above neutral), while WildWatcher responses were more mixed (median = 4, but closer to neutral) (Figure 12).
- Knowledge from expert interaction (Q18.3). Participants in Amphibian and Reptile Mapping felt more positively about learning from expert interactions (median = 4) (Figure 12) compared to those in WildWatcher (median = 3), showing a significant difference ($p = .028$) (Table 14).

- Pre-existing knowledge (Q18.6): Amphibian and Reptile Mapping users were more likely to disagree that their knowledge was already sufficient before joining (median = 2), suggesting they experienced more learning through participation (Figure 12). WildWatcher participants were more neutral (median = 3). These found a statistically significant difference (p = .002) (Table 14).
- Both projects primarily attracted non-expert participants, though WildWatcher included a higher proportion of experts (36.4%) compared to Amphibian and Reptile Mapping (20.7%). This difference was statistically significant but weak (Chi-square p = .002; Cramer's V = .177) (Table 14).

Table 14. Knowledge-related questions test results

Question	Mann-Whitney U	Mann-Whitney U of the median Q18, Q18.1, Q18.3	Chi-square/ Cramer's V
	p-value	**p-value**	**p-value**
Q16 & Q17 Level of expertise			0.002*/0.177
Q18. I feel that my knowledge of species has been expanded by using the website	<.001*		
Q18.1 I feel that my knowledge of species has been expanded by using the project phone application.	0.055	0.100	
Q18.3 I feel that my knowledge of species has expanded through interaction with experts from the project.	0.028*		
**Q18.6 I had sufficient knowledge before participating in the project; my knowledge has not changed	0.002*		
Q18.7 Participation in the project made me realize the importance of my observations.	0.463		
Q18.8 I would have been happy to receive personal training before starting my participation in the project.	0.879		
Q18.9 I expanded my knowledge necessary to participate in the project with the help of external information sources (e.g., specialist books, other websites, articles, Facebook groups).	0.360		

Note: *Asterisks indicate p-values showing significant differences between the two projects (p<.05). **Reverse scoring applied

For other knowledge-related questions (Q18.1, Q18.7, Q18.8, Q18.9), the Mann-Whitney U test showed no significant differences between the groups (all p > .05) (Table 14). Both projects showed similar responses, with neutral to positive perceptions of knowledge gain from the mobile app, recognition of the value of observations, and a moderate interest in external information sources and personal training (Table 14. Knowledge-related questions test results).

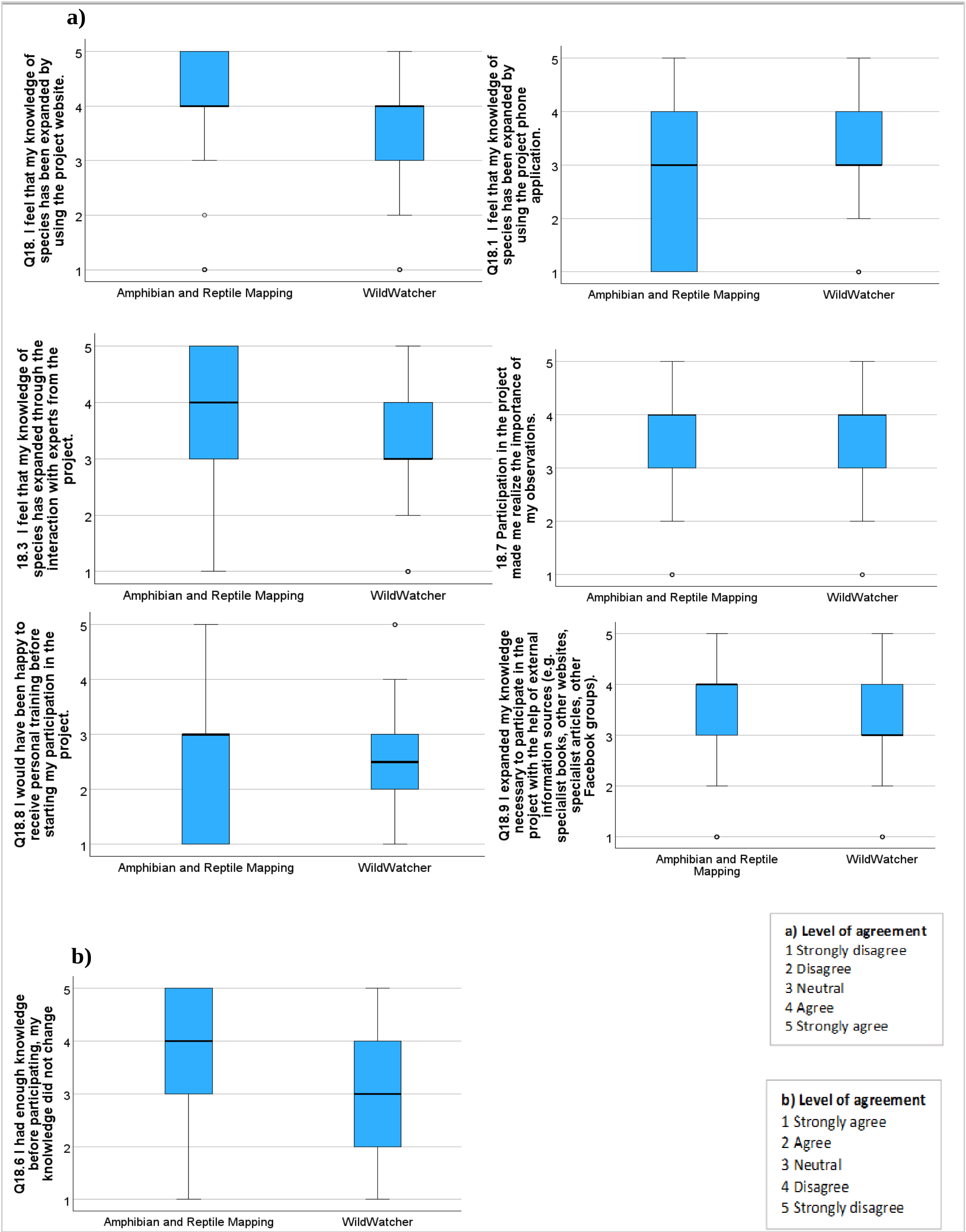

Figure 12. Knowledge-related questions, boxplot results

4.3.4. Attitudes and behaviours

Participants' attitude and behaviour responses in the Amphibian and Reptile Mapping and WildWatcher projects clustered toward positive ratings, with median scores typically at 4 (Agree) and interquartile ranges spanning Neutral to Strongly Agree across items, indicating broadly pro-environmental orientations in both projects (Figure 13).

A single targeted difference emerged; analysis with the Mann-Whitney U test revealed a significant difference between the two projects regarding efforts to minimize disturbance to species and their habitats (Q20; p = .014) (Table 15). Amphibian and Reptile Mapping participants reported a higher level of agreement (median = 4). In contrast, WildWatcher participants were more neutral (median = 3) (see Figure 13).

Table 15. Attitude and behaviour-related questions test results

Question	**Mann-Whitney U**	**Mann-Whitney U of the median Q20, Q20.1, and Q20.2**
	p-value	p-value
Q20. As a result of the project, I minimized the disturbance of species and their environment in the natural environment.	0.014*	0.678
Q20.1 I share with others my experience in the project	0.938	
Q20.2 I encourage my family and friends to participate in the project.	0.755	
**Q20.3 My attitude towards nature has not changed. I have behaved in a nature-friendly way before, and the project did not change that.	0.427	

Note: *Asterisks indicate p-values showing significant differences between the two projects (p<.05). **Reverse scoring applied

For other attitude and behaviour questions (such as sharing experiences, encouraging others to participate, and maintaining environmentally friendly behaviours), no significant differences were found between the projects (all p > .4; see Table 15). Both projects typically agreed with these statements.

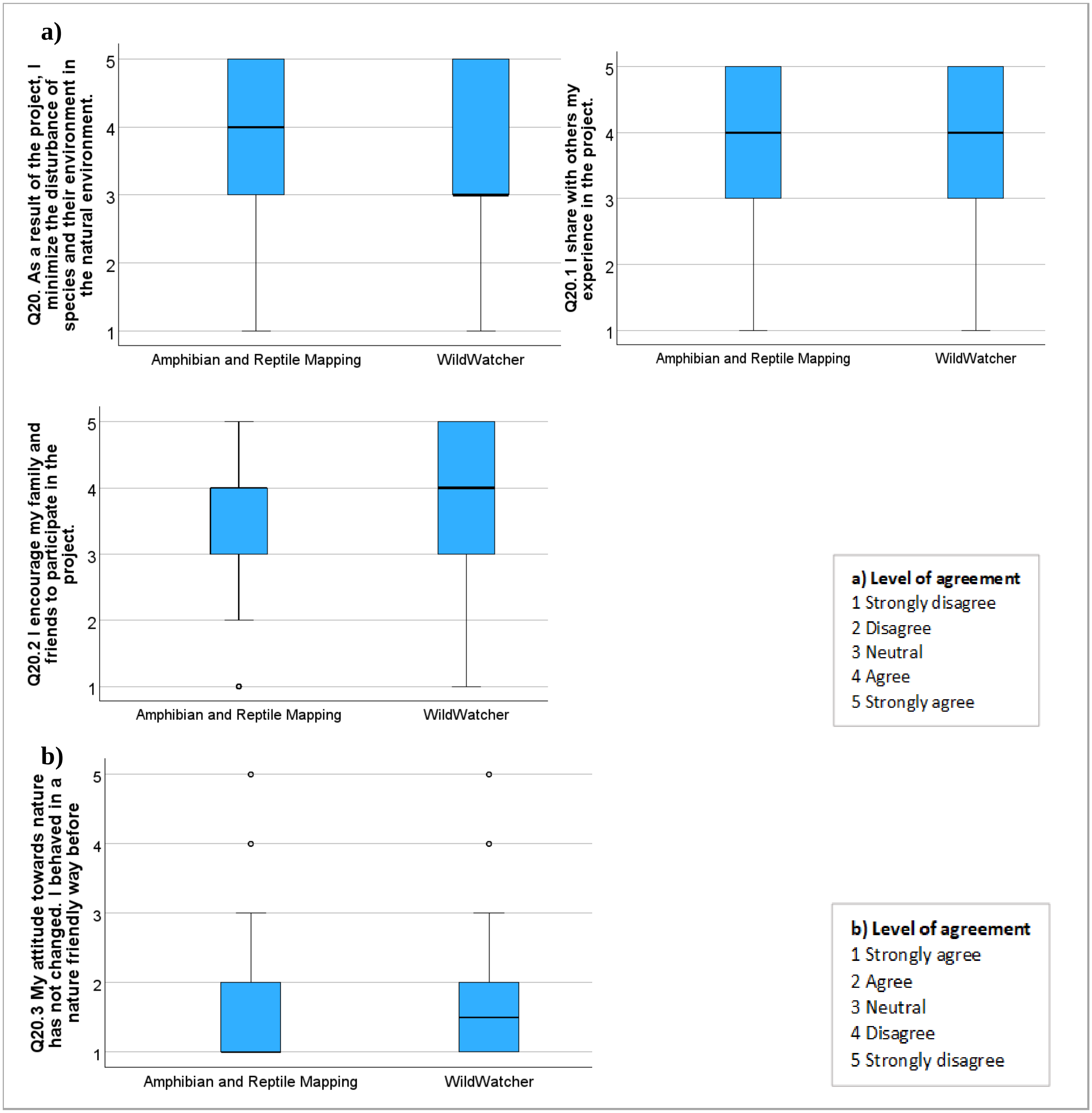

Figure 13. Attitude and behaviour-related questions boxplot results

For Q20.3 ("My attitude towards nature has not changed. I have behaved in a nature-friendly way before, the project did not change that"), the WildWatcher median lies between "strongly agree" (1) and "agree" (2), suggesting most participants already considered themselves to have a nature-friendly behaviour before the project (see b section of Figure 13). However, the Mann-Whitney U test result (p = 0.427) indicates no significant difference between the two groups, suggesting that both projects attracted similarly predisposed, nature-friendly participants (Table 15).

4.3.5. Motivation

In both the Amphibian and Reptile Mapping and WildWatcher projects, participants' motivation responses clustered at medians of 3–5, indicating moderate to strong endorsement overall, with tighter distributions for website- and expert-related items.

Two targeted differences emerged; the Mann-Whitney U test revealed significant differences between: personal interest in the project species (Q19.4; p = .001) and research purposes (Q19.6; p = .005) (see Table 16). For personal interest in the project species as a motivation (Q19.4; p = .001), although both groups had the same median score of (5=Strongly Agree) (see Figure 14), WildWatcher participants' responses were more tightly grouped at the top of the scale, reflected by a lower variance (0.620 compared to 1.024 for Amphibian and Reptile Mapping). This indicates that WildWatcher participants were more consistently and strongly motivated by personal interest in the species, while motivation levels among Amphibian and Reptile Mapping participants were more varied (Table 16).

Table 16. Motivation-related questions test results

Question	Mann-Whitney U p-value
Q19. Leisure/family activity	0.295
Q19.1 My responsibility towards nature	0.119
Q19.2 Meet other people with a similar interest.	0.658
Q19.4 Personal interest in the project species	0.001*
Q19.5 Desire to learn	0.539
Q19.6 Research purposes	0.005*

Note: Asterisks indicate p-values showing significant differences between the two projects (p<.05).

Regarding the motivation for participation in research, a significant difference (Q19.6; p = .005) was found. WildWatcher participants reported higher motivation (median = 3, Neutral) with a wider spread of responses, while Amphibian and Reptile Mapping participants showed consistently lower motivation for research (median = 2, Disagree).

For other motivations, including leisure or family activity (Q19; p = .295), responsibility towards nature (Q19.1; p = .119), meeting people with similar interests (Q19.2; p = .658), and desire to learn (Q19.5; p = .539), no significant differences were found between the projects (Table 16). For these items, both groups showed similar patterns, with median scores ranging from (3=Neutral) to (4=Agree) and interquartile ranges typically spanning from Neutral to Agree or Strongly Agree (Figure 14).

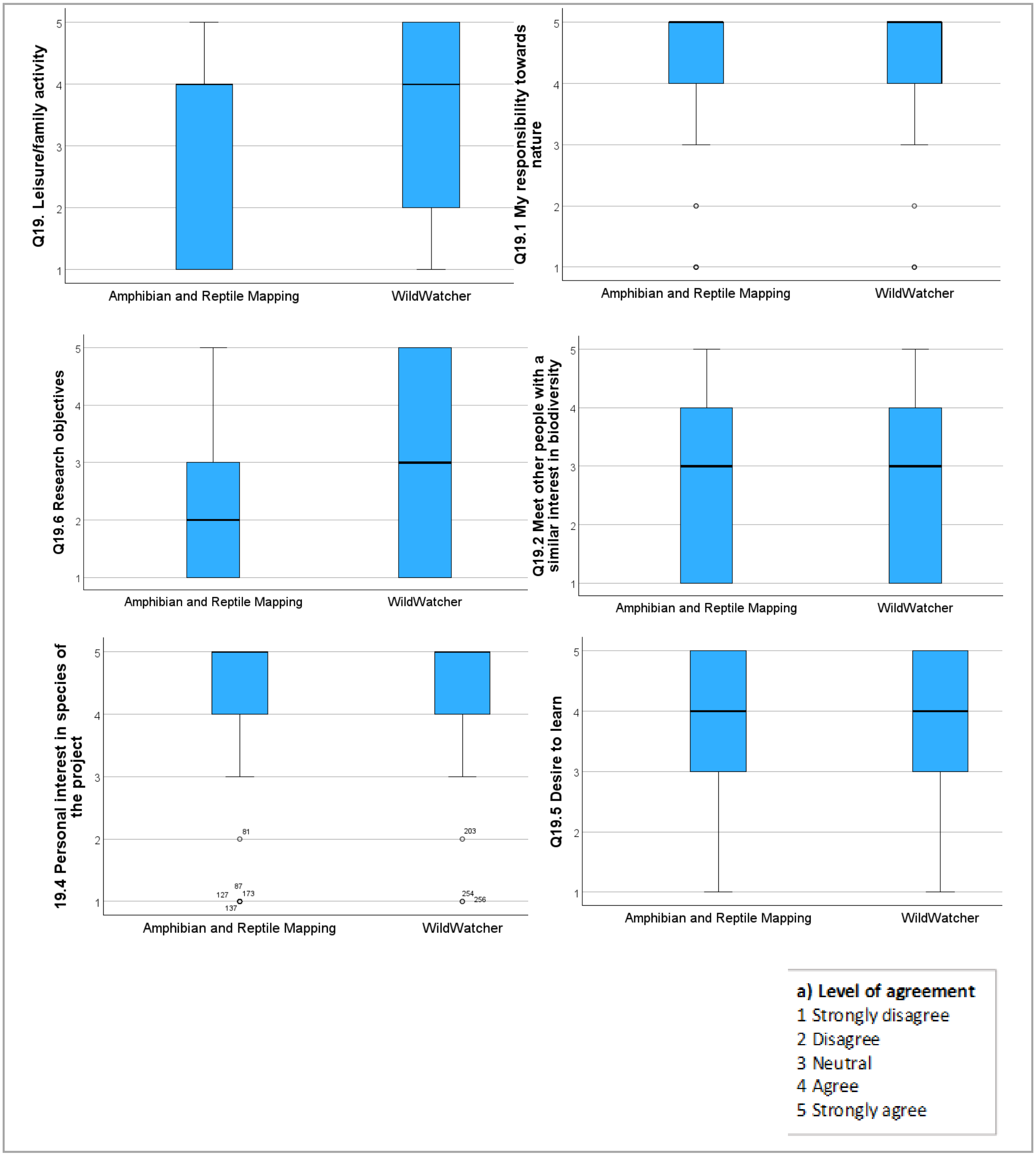

Figure 14. Motivation-related questions boxplot results

In summary, participants in both projects reported moderate to strong motivation across most categories, but WildWatcher participants were more consistently driven by personal interest in the species and showed greater motivation for research purposes.

4.3.6. Discussion of the results of the comparative analysis of the questionnaires prepared for the participants of two Hungarian NCCS projects

Demographics of participants

Both NCCS projects attracted predominantly middle-aged, well-educated participants, with about a third having professional links to nature conservation. This demographic pattern is widely reported in NCCS literature, where higher education and middle-to-older age groups are common among volunteers. However, a notable difference (Pateman et al., 2021; West et al., 2021) emerged in gender balance: Amphibian and Reptile Mapping was male-dominated, while WildWatcher saw greater female participation. This may be attributed to the nature of the target taxa and fieldwork requirements; herpetofauna projects often require more challenging fieldwork and have traditionally attracted more male participants, whereas projects featuring easily observable and familiar species tend to appeal to a broader, more gender-diverse audience (Nicholson et al., 2008; Bonney et al., 2016; Reniers et al., 2016; Pateman et al., 2021). These findings suggest that project design and target species can influence the inclusivity and diversity of NCCS initiatives.

Participation patterns and technology use

Social media proved to be the most effective tool for recruiting participants to both projects, far superior to traditional media channels such as newspapers or television. This is consistent with broader trends in citizen science, where digital platforms now play a central role in outreach and engagement (Oliveira et al., 2021). However, it should be noted that the online nature of the survey may have introduced bias, potentially underrepresenting individuals who are less active online.

When it comes to submitting observations, both projects showed a preference for web-based platforms over mobile apps, though WildWatcher participants were somewhat more likely to use the app. This suggests that while mobile technology is gaining traction, web interfaces remain dominant, especially for tasks requiring more detailed data entry (SPOTTERON, 2019). User satisfaction with both technological interfaces was high, in line with studies emphasizing the importance of intuitive, user-friendly platforms for sustained engagement (Newman et al., 2012; Lemmens et al., 2021).

Despite positive feedback on technology usability, neither project achieved regular monthly engagement among most users. This pattern is common in NCCS, where a small group of highly active participants contribute most data, while the majority engage sporadically (Lemmens et al., 2021; Etter et al., 2023; Hognogi et al., 2023). Additionally, the strong seasonality of certain taxa (such as amphibians and reptiles) further influences participation rates, with peaks corresponding to periods of increased species activity.

Expertise level and knowledge gain

The two projects differed in the expertise levels of their participants. WildWatcher attracted a broader range of experts, likely due to its diverse set of target species, while Amphibian and Reptile Mapping's narrower taxonomic focus may have limited its appeal to specialists. This finding contrasts with some literature suggesting that specialist projects tend to attract more experienced volunteers, while generalist projects draw more novices (Bonney et al., 2016; Pateman et al., 2021). This discrepancy indicates that contextual factors, such as project design and outreach, can significantly shape the participant pool.

Participants in Amphibian and Reptile Mapping reported greater perceived knowledge gain from the project website, likely due to the in-depth, species-specific information provided. In contrast, WildWatcher's focus on common and easily recognized species may have resulted in less perceived learning, as many participants were already familiar with the taxa. This interpretation is similar to findings of Santori et al. (2021), where participants in specialist citizen science projects, such as TurtleSAT, reported substantial knowledge gains about the target species, with 70% noting increased understanding of turtles. In contrast, participants in broader projects focused on various plant species did not show significant knowledge improvement (Jordan et al., 2011; Crall et al., 2013). Furthermore, direct interaction with experts was rated more positively in Amphibian and Reptile Mapping, where ongoing support and feedback were more readily available, an approach shown to enhance knowledge and motivation in citizen science (Callaghan et al., 2020; Peter et al., 2021).

Attitude, behaviour and motivation

Participants engaged with the Amphibian and Reptile Mapping project exhibited a stronger commitment to minimizing disturbance to wildlife and habitats than those participating in the more generalist WildWatcher initiative. This finding is consistent with the results of Santori et al. (2021), who reported that projects targeting sensitive or less familiar taxa, and which provide explicit guidance on best practices, are more likely to foster a heightened sense of responsibility and conservation-oriented attitudes among volunteers. However, this outcome contrasts with the observations of Lewandowski & Oberhauser (2016), who noted that multi-species citizen science projects, particularly those involving more familiar or less sensitive taxa, often encounter challenges in effecting substantial changes in participant attitudes and behaviours.

Regarding respondents' motivation for participation, WildWatcher participants expressed a greater personal interest in the target species and research objectives, yet both projects demonstrated similar patterns in terms of motivations related to leisure, family involvement, environmental responsibility, and social interaction. These results are in line with previous research indicating that such core motivational factors are prevalent across a wide range of citizen science projects, irrespective of their taxonomic or thematic focus (Rotman et al., 2012; West & Pateman, 2016). Collectively, these findings underscore the importance of targeted project design in promoting conservation-minded behaviours, while also highlighting the persistence of universal motivational drivers within the NCCS community.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Following the objectives and research questions, the conclusions integrate four evidence streams: the targeted literature review informing framework development, evaluation of eight NCCS projects via the conceptual/operational evaluation framework, comparative analyses of observation databases, and questionnaires conducted among participants for two selected NCCS projects. The conclusions are organized by objective and research question.

Objective 1: To develop a conceptually grounded evaluation framework for NCCS projects, structured around three core dimensions (science, nature conservation, and participants' development) that is applicable across multiple countries.

Research question: 1.1 What are the key components of a three-dimensional conceptual framework for evaluating NCCS projects?

Based on the literature review, a conceptual framework was developed that includes three dimensions (science, nature conservation, and participants' development). It provides a comprehensive basis for evaluating specifically nature conservation citizen science (NCCS) projects, while remaining sufficiently general for application in other countries. Within science, the core components include methodology, data quality, and data management; within nature conservation, the components focus on data use in monitoring, management, and conservation policy/decision-making pathways; and within participants' development, the components cover training, additional learning support strategies, and measurement strategies for participants' personal development.

Research question: 1.2 How can these components be translated/operationalized into a practical, user-friendly three-dimensional evaluation framework for NCCS projects' performance assessment?

Grounded in the three-dimensional conceptual framework, its components were operationalized into a practical, user-friendly three-dimensional evaluation framework by translating each component into several criteria and related binary yes/no questions, as well as applying normalized scoring, enabling clear, comparable assessment across science, nature conservation, and participants' development. When empirically applied to the eight Hungarian NCCS projects, the instrument differentiated performance and qualitative evidence to explain project divergences, demonstrating both validity and interpretability. The tool is simple and easy to use. Managers can use it for self-checks and planning, and external reviewers can use it to target improvements. The questions are general, not specific to the Hungarian context; therefore, they can be applied in other countries as well, where basic project information is available, producing comparable profiles and clear next steps

Objective 2: To assess the scientific contribution of selected Hungarian NCCS projects.

Research question: 2.1 How do NCCS projects ensure data quality?

The results of the evaluation of the data quality component of the science dimension using the evaluation framework, applied across eight Hungarian NCCS projects, showed that all projects implement multiple, layered data quality-assurance strategies: expert validation is a consistent practice of all projects; requests for additional information from contributors when needed; targeted site visits to resolve inconsistencies; and support from institutional expertise. The focused analysis of two long-running NCCS project databases corroborates this in practice: more than 90% of observations were validated in both datasets across years, with only a small recent increase in unchecked records in WildWatcher (2023–2024) relative to Amphibian and Reptile Mapping (Chi square test, $p < .001$), confirming that data validation is performed and embedded throughout the years.

Research question: 2.2 Are the outcomes of NCCS projects scientifically robust?

Based on the evaluation of the science dimension, across eight projects using the evaluation framework, there are scientifically robust outcomes: projects collectively scored 660/800 in the science dimension, reflecting strong methods, validation, and data management. Complementing these results, the comparative analysis of the two NCCS projects shows that the Amphibian and Reptile Mapping provides high, long-term volume and range (74,415 observations, multiple peak years) with balanced coverage of target taxa, while WildWatcher provides a steady annual flow (17,484 observations, 2009–2024) dominated by mammals and complemented by other groups. Together, these longitudinal databases show consistent data production, taxonomic representativeness aligned with project aims, and sufficient volumes for robust inference, confirming the scientific robustness of the selected Hungarian NCCS projects.

Objective 3: To assess the nature conservation role of selected Hungarian NCCS projects.

Research question: 3.1 How can NCCS projects contribute directly to the monitoring of species?

Based on the evaluation of the nature conservation dimension of the eight projects using the evaluation framework, this dimension emerged as the second-strongest across the eight selected projects, totalling 533/800 points. The Common Bird Monitoring Program, Amphibian and Reptile Mapping, and WildWatcher each achieved the maximum 100 points. Consistent with literature emphasizing the value of long-term continuity, projects with longer operational histories (e.g., Amphibian and Reptile Mapping, WildWatcher, Common Bird Monitoring) perform especially well on nature conservation components, reflecting established roles in monitoring of species nationwide; integration into national biodiversity infrastructures such as the Hungarian Nature Conservation Information System (TIR) (e.g., WildWatcher), while projects like the Common Bird Monitoring Program, Arthropods, and Butterfly-Net have identified new populations demonstrating direct contribution on species monitoring in Hungary.

Research question: 3.2 How are NCCS project outcomes utilized in species management?

The evaluation of the species management component (nature conservation dimension) across eight projects using the evaluation framework shows that project outcomes are actively utilized in species management, with validated citizen-generated data triggering concrete interventions across control, mitigation, and habitat protection, mainly in older projects. The Common Bird Monitoring Program led the nature conservation dimension with the highest score (257/300), followed by Amphibian and Reptile Mapping (256/300) and WildWatcher (241/300) as the next best performers. Moreover, (5/8 projects) met the component of environmental management, evidencing direct management uptake by the majority of analysed projects. Open-data adopters (e.g., Arthropods) enabled new species records and invasive detections, while Butterfly-Net observations led to a newly recognized butterfly population and subsequent habitat protection by the Őrség National Park Directorate. Taken together, these findings show that validated NCCS outcomes routinely inform and accelerate species management decisions and actions.

Research question: 3.3 How are NCCS project outcomes utilized in policies and conservation actions?

Based on the evaluation of the policy component (nature conservation dimension) of the eight projects using the evaluation framework, results indicate that collectively, policy uptake remains uneven across the analysed NCCS projects. However, mature initiatives with long-term databases and established institutional linkages have created clear pathways from citizen-generated evidence to conservation policies and official reporting (3/8 projects scored Policy component). WildWatcher data feeds the Hungarian Nature Conservation Information System and supports Article 17 reporting under the EU Habitats Directive, Butterfly-Net records on OpenBioMaps improve access for decision-makers. Amphibian and Reptile Mapping regularly supplies datasets to the European Atlas of Amphibians and

Reptiles and EU reporting, and the Common Bird Monitoring Program underpins EU-wide monitoring and Hungary's annual bird atlas.

Objective 4: To assess the impact of selected NCCS projects on participants' development.

Research question: 4.1 What motivates citizens to get involved in the selected NCCS projects?

Based on the results of questionnaire surveys conducted among participants of the two selected projects, participants of Amphibian and Reptile Mapping are highly motivated overall (medians 4–5) by broadly shared motivations of learning, responsibility toward nature, leisure/family activity, and meeting like-minded people. WildWatcher shows stronger, more consistent motivation from personal interest in species (Q19.4; $p = .001$; both medians = 5, but lower variance 0.620 vs. 1.024) and higher motivation for research purposes (Q19.6; $p = .005$; median = 3 vs. 2 in Amphibian and Reptile Mapping).

Research question: 4.2 How do NCCS projects influence the knowledge of participants?

Based on the evaluation of the participants' development dimension across eight projects using the evaluation framework, it was revealed that this dimension lags behind the science and nature conservation dimensions (471/800), largely because most initiatives lack systematic protocols to assess and knowledge. Butterfly-Net stands out as the only project that incorporates structured knowledge-gain measurements into its methodology. Addressing this gap, this study offers the first direct comparison of two select NCCS projects (Amphibian and Reptile Mapping and WildWatcher) through questionnaire surveys conducted among participants, demonstrating that involvement in NCCS fosters knowledge gain in distinct ways (medians above neutral 3–5 across knowledge gain). Specialized NCCS projects focusing on target species, such as Amphibian and Reptile Mapping, yield greater participant knowledge gains than generalist projects like WildWatcher ($p=.014$), which mainly broaden participation but offer smaller learning outcomes.

Research question 4.3: How do NCCS projects influence participants' attitudes and behaviours?

Based on the evaluation of the measurement strategies for participants' personal development component (participants' development dimension) across eight projects using the evaluation framework, none of the eight projects formally evaluate changes in attitudes or behaviours. Nevertheless, coordinator interviews indicate pro-conservation orientations where explicit low-impact norms (codes of conduct, handling guidance, seasonal access rules) are embedded in project practice. Several projects provide feedback to reinforce engagement, attitude, and behavioural change, but the effects of such practices remain unevaluated. Questionnaire surveys conducted among participants of the two selected projects corroborate this pattern. Amphibian and Reptile Mapping participants report stronger agreement with minimizing disturbance than WildWatcher participants ($p = .014$; medians 4 vs. 3), while all other attitude/behaviour items show no significant differences between projects (all $p > .4$) and are generally endorsed (median = 4).

5.2. Recommendations

Policymakers should actively promote the adoption and endorsement of standardized evaluation frameworks for NCCS projects. By encouraging project coordinators and funding agencies to institutionalize periodic evaluations using adaptable and recognized frameworks such as the one developed in this study, ongoing monitoring of scientific rigor, nature conservation, and participants' development can be ensured. Regular, standardized assessments improve data reliability and support continuous project improvement through adaptive management. This, in turn, strengthens the credibility and acceptance of NCCS data in conservation policy-making processes, increasing the likelihood that NCCS outcomes effectively inform conservation policies and decision-making. Establishing such evaluation standards will bridge the gap between citizen-generated data and practical environmental governance, fostering greater integration and impact of NCCS initiatives.

It is recommended that future NCCS projects prioritize establishing and maintaining strong institutional backing and collaboration with scientific organizations. The success of the projects analysed in this study was consistently supported by robust institutional partnerships, which played a critical role in ensuring data quality and long-term sustainability. Even projects that began as independent initiatives, such as Arthropods, have increasingly sought organizational support, underscoring the recognized value of institutional collaboration. Strengthening these partnerships should therefore be a central strategy for any NCCS project aiming to achieve high standards of data reliability and enduring impact.

It is recommended that NCCS projects adopt open dataset principles by making their databases freely accessible, as this approach has been shown to significantly enhance scientific output and foster wider data use. The experience of the Arthropods project in Hungary, which has fully embraced open access and developed a large, widely utilized database, demonstrates the substantial benefits of open data practices. By following this example, other projects can increase the visibility and impact of their results, promote greater collaboration, and facilitate the production of scientific publications based on project outcomes, an area where further progress is still needed in the Hungarian NCCS context.

Strengthening NCCS projects of evaluation protocols to more effectively capture participants' development is needed, including changes in knowledge, skills, and engagement over time. Doing so would provide a more comprehensive understanding of project effectiveness beyond scientific outputs alone and highlight the social and educational impacts of citizen science. Improved participant-focused evaluation would also support the design of future initiatives that are better tailored to foster meaningful involvement, ultimately maximizing the benefits of NCCS projects for science, nature conservation and participants equally.

To maximize the impact and usability of NCCS data, future projects should prioritize the integration of rigorously validated, multi-taxa datasets with comprehensive metadata into national biodiversity information systems. The successful inclusion of WildWatcher data in the Hungarian Nature Conservation Information System (TIR) illustrates how such integration can significantly enhance the scientific and conservation value of citizen science efforts. Based on the focused analysis of the two long-term databases and their consistently high validation rates, incorporating these datasets into national systems is a logical next step. Aligning project outputs with national data standards not only improves data accessibility and reliability but also strengthens the role of NCCS in supporting evidence-based conservation, long-term biodiversity monitoring, and informed policy-making.

It is recommended to implement longitudinal mixed-methods research designs to effectively track changes in participants' knowledge, attitudes, skills, and conservation-related behaviours over time. This approach should include standardized pre- and post-participation assessments to provide objective measures of impact, while moving beyond reliance on self-reported data by integrating qualitative methods such as interviews and observations. Employing this comprehensive evaluation strategy will yield robust evidence of participants' development and help inform the design of more effective and impactful nature conservation citizen science projects

Finally, to further strengthen the evaluation of NCCS projects and ensure a more representative understanding of participants' experiences, it is advisable to broaden the reach of the questionnaires to include a wider pool of participants. Expanding the survey distribution (potentially by incorporating a brief, targeted questionnaire focused on participants' development criteria) would help capture a more diverse range of perspectives and experiences. This approach is particularly important given that the online format of the initial survey may have introduced bias, potentially underrepresenting individuals who are less active online. By reaching out through additional channels and formats, future evaluations can minimize this bias, enhance the inclusivity of the participants' sample, and provide deeper insights into participants' development dimension and the contributors involved in NCCS projects.

Further research is recommended to identify the key drivers of participants' knowledge gains by repeatedly assessing the same cohort with standardized pre-post-instruments and interim follow-ups, enabling causal comparisons over time. This should test how project features—such as training intensity, expert interaction, feedback frequency, and task complexity—moderate learning trajectories, so that project design can be adaptively tailored to participants' needs and maximize knowledge gain impact, which can be applied as well to measure attitude and behaviour change. In parallel, it is recommended that future research explore how to address open-data practices, (as it was one of the weakest performed components of the evaluated projects in this study), by protecting sensitive species while maintaining reuse (for example, location sharing) and documenting protection methods in metadata, using role-based access for trusted users or authorities to preserve conservation value, and evaluating effects on volunteer trust, motivation, and knowledge.

6. KEY SCIENTIFIC FINDINGS AND IMPORTANT OUTPUT

1. **A key scientific contribution of this dissertation is the development of a non-country-specific conceptual framework for Nature Conservation Citizen Science (NCCS) projects that uniquely integrates three essential dimensions (science, nature conservation, and participants' development).** This general (non-country-specific) evaluation framework for NCCS projects is structured around three key dimensions, with three components per dimension. The science dimension comprises data quality, validation, and data management; the nature conservation dimension comprises data use in monitoring, management, and policy; and the participants' development dimension comprises training, knowledge gain, and attitude/behaviour change.
2. **Building upon the conceptual framework, a second key contribution is the development of a three-dimensional evaluation framework, specifically designed to assess the performance of NCCS projects.** The framework operationalizes the conceptual framework and its nine components into 18 criteria that are translated into yes/no questions. It can be easily used by project coordinators and can be a base for cross-project comparison along all three dimensions.
3. **The empirical application of the three-dimensional evaluation framework to eight Hungarian NCCS projects showed uneven performance across dimensions.** From the 800 possible maximum points, the projects performed strongly in the science dimension (660 points), moderately in nature conservation (533 points), and weakest in participants' development (471 points).
4. **Based on the comparative analysis of the two selected observation databases, both NCCS initiatives accumulated substantial databases over more than a decade, maintaining consistently high validation rates (>90%) with relatively few unchecked or invalid records.**

   The analysis also revealed that WildWatcher exhibited a slightly higher proportion of unchecked records in recent years compared to Amphibian and Reptile Mapping, a significant difference (Chi-square test, $p < .001$; Cramér's V = .276), most pronounced in 2023–2024.
5. **Based on the results of questionnaire surveys conducted among participants of two selected projects, using a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree), respondents reported moderate-to-high knowledge gains (medians 3–5) alongside broadly pro-conservation attitudes and behaviours (medians ≈ 4) in both projects.** Amphibian and Reptile Mapping showed significantly higher gains of knowledge via the website (Mann-Whitney

U test, $p < .001$) and expert interactions (Mann-Whitney U test, $p = .028$) (medians 4), while Wildwatcher showed neutrality (medians 3). Amphibian and Reptile Mapping showed significantly stronger commitment to minimizing disturbance (Mann-Whitney U test, $p = .014$) (median 4) than WildWatcher, with most respondents being neutral (medians 3). Both groups endorsed intrinsic motivations, while WildWatcher was more driven by personal interest in species (Mann-Whitney U test, $p = .001$) and research purposes (Mann-Whitney U test, $p = .005$).

7. SUMMARY

Citizen Science (CS) engages volunteers in scientific research and environmental stewardship, using digital tools to boost participation and data collection. NCCS, a crucial branch of CS, delivers long-term biodiversity data needed for species monitoring, effective conservation management, and policy formulation. While NCCS is well established in Western Europe, it is still emerging in Central and Eastern Europe, including Hungary, where challenges persist in data quality, representativeness, and policy integration. Current evaluations often overlook this complexity, underscoring the need for a tailored, comprehensive approach.

This study evaluates Hungarian NCCS projects across three dimensions: science, nature conservation, and participants' development. A multidimensional evaluation framework, based on the literature, was developed to assess eight selected NCCS projects across the three dimensions using clear binary scoring criteria for robust comparison. The mixed-methods study involved three phases: (1) qualitative interviews with coordinators of eight Hungarian NCCS projects (2) quantitative analysis of species long term databases from two projects (Amphibian and Reptile Mapping and WildWatcher) focusing on science and conservation dimensions, and (3) survey-based comparison of participants' experiences regarding motivation, knowledge, attitudes, and behaviours of the participants' development dimension. Data collection adhered to strict ethical standards, employing qualitative coding and statistical analyses with measures ensuring reliability and inclusiveness.

Results showed that the eight selected projects were mostly linked to NGOs or scientific bodies, steadily growing in participation and observations. The scientific dimension was strongest, with most projects scoring above 70 points, emphasizing technology use, expert validation, and peer-reviewed outputs; only Arthropods provided open raw data. All projects contributed vital conservation data, with long-term projects aiding direct conservation actions and policy, and Arthropods' open data revealing new species. Participant development varied most: Butterfly-Net led with hands-on training, while others relied on digital tools; formal learning assessments were rare despite common expert contact.

Regarding the comparison of two project databases, Amphibian and Reptile Mapping showed over 74,000 validated records of 34 species with seasonal peaks; observations were collected primarily via web interfaces. WildWatcher collected over 17,000 observations of 21 species more evenly year-round, with higher mobile app use. Both had high validation rates (~95% and ~90% respectively).

Surveys of 291 participants revealed mostly well-educated, middle-aged volunteers outside Budapest; Amphibian and Reptile Mapping had more males, and WildWatcher gender was balanced. First contact with the project came mainly from social media. Engagement was seasonal for Amphibian and Reptile Mapping and steady for WildWatcher. The former fostered stronger conservation attitudes and learning, supported by expert interaction; the latter attracted volunteers motivated by personal interest and scientific goals.

The evaluation of NCCS projects presented in this consideration highlights the need to integrate scientific rigor, nature conservation, and participants' development comprehensively to strengthen NCCS projects in Hungary and similar contexts. The findings provide practical guidance for policymakers, practitioners, researchers, educators, and volunteers to enhance data quality, participants' learning, conservation outcomes, and project design, with the adaptable framework suitable for broader application.

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9. APPENDICES

9.1. Appendix 1. Interview questions

Questions for project managers' interviews

NCCS project description

1. Please tell a few words about yourself and your main tasks in the project in general. (Profession, organizations where you contribute or work)
2. How did you get to know citizen science? How was your first encounter with it?
3. How would you define Citizen Science (CS)?
4. Which CS project do you manage or participate in?
5. Why did you decide to launch a CS project?
6. What is the main purpose of your CS project?
7. What species do you focus on, in the project?
8. What kind of data is collected?
9. What is your role, functions, or responsibilities in the CS project?
10. What are other roles in the project? How many experts/assistants are involved in the operation of the project?
11. How long has the project been running?
12. Can you detect stages in the development of the project? What are these and can you define time periods for these stages?
13. Where is the CS project implemented? What is the geographical scope of your CS project?
14. How do you reach the participants?
15. How can the technical background of the CS project be characterized? What software, platforms, and devices are used by the managing organization and by the participating citizen scientists?
16. How the CC project is financed?

17. How many volunteers have participated in the project so far? What is the approximate average number per year? Are there fluctuations in the number of participants?

18. What characteristics do your citizen science volunteers have (age, profession, location)?

19. Do you detect how the collected data are distributed among citizen scientists? (e.g., are there very active people reporting many times or it is more evenly distributed)?

20. Are you collaborating with other institutions in your project? Is your project affiliated to any institution?

Science Dimension

21. Does the citizen science project have a structured methodology? What is the protocol/task that participants perform?

22. Was a scientific question formulated before starting the project?

23. How data is validated?

24. What kind of professionals are involved during data validation process?

25. What is your experience with the validation?

26. To what extent do you consider the outcome of the CS project scientifically sound?

27. Have you made data of your CS project and the results available to the science community? How?

28. Have you participated in scientific conferences with the results or data from the CS project?

29. Have you published the results of the CS project in scientific journals? where and when? If not, why?

30. Have data or results from your CS project been used in any other scientific study or scientific project? Is your CS project part of any research project? If yes, what is the role of CS in the scientific project?

31. Are there other ways your CS project is contributing to science?

32. How do you see the relation between Citizen Science and Science?

Nature Conservation Dimension

33. Are data collected in your CS project used in nature conservation? If yes, how? (e.g., official monitoring system, species or ecosystems management, nature conservation policy formulation or decision-making) If not why not?

34. How in your opinion could data from CS projects be used more for conservation purposes? How can you reach that goal?

35. What evidence do you have about the impact of your CS project on nature conservation?

36. How do you measure that evidence?

37. Does your project actively engage participants in environmental conservation issues? How?

38. Do you think your CS project can influence conservation policy and management at local, national, or European levels? How?

39. How do you see the relation between Citizen Science and Nature Conservation?

Participants' development

40. In your view, what motivates participants to get involved in your CS project?

41. Have you surveyed it or measured it?

42. Are the participants required to have any specific knowledge before they get involved in the CS project?

43. Is there any assessment of the participant's knowledge before starting the project? If yes, how do you do it?

44. How is the scientific knowledge behind the project transferred to participants?

45. Do you provide formal or informal training for the participants? How do you conduct it? How long does it take?

46. In your view how does your CS project help to enhance the conservation knowledge of the participants? Do you monitor or measure it somehow?

47. How does the CS project help to enhance the conservation behaviors of the participants? Do you monitor or measure it somehow?

48. Do you believe that participation in your citizen science project has increased participants' engagement in conservation?

49. Which strategies do you use to encourage participation in conservation activities outside or after your project?

50. How do you see the relation between Citizen Science and Environmental Education?

Strengths and Challenges

51. What do you consider a successful CS project in general?

52. What do you see as the main results/achievements of your project? Can you describe them?

53. What were the factors that ensured the success of your citizen science project?

54. Which challenges have you encountered during the CS project process? What are your future plans regarding your CS project development?

55. If you have any publications in Hungarian or English about your project, please could you share them with me.

56. Can you suggest other Hungarian conservation-related CS projects and their managers?

57. Do you know of any conservation-related CS projects in CEE countries?

58. We value your opinion and support very much. If you have any additional information, comments or further contacts you think we should approach, please let me know.

9.2. Appendix 2. Questionnaires

Questionnaire for participants of Amphibian and Reptile Mapping

Dear participants of the Herptérkép citizen science project, welcome to our survey!

We invite you to take part in the survey which will take you appr. 20 minutes to complete.

Information on the research

The questionnaire is part of a Ph.D. research on conservation-related citizen science conducted in collaboration with MME. It aims to assist the further development of the citizen science project Herptérkép.

We refer to Citizen Science as the participation of non-scientists in one or more stages of scientific research to produce new knowledge it will be useful for scientific and conservation purposes.

Data protection

The data of the questionnaires are treated confidentially in accordance with the ethical principles of the Code of Scientific Ethics of the Hungarian Academy of Sciences and the European Code of Conduct for Research Integrity, and in accordance with the rules of the EU GDPR. The analysis is anonymous and only aggregated data is disclosed. Participation in the survey is voluntary

By checking the box below, you indicate that you have read the information, below and consent to participate in the ECSP survey prepared by Johanna Soria and the Herpterkep team of MME

○ Consent

Thanks for participating.

A. GENERAL INFORMATION ABOUT THE PARTICIPATION

1. Through which channel did you hear first about Herptérkép? (You can choose more than one option)
   - MME (Birdlife Hungary)
   - MME (KHVSZ amphibian and reptile protection department)
   - Website of MME
   - MME KHVSZ website
   - Social media
   - TV, radio.
   - Newspaper
   - Colleagues
   - Friends
   - Other (please specify) ____________________

2. For how many years have you been participating in the CS project?

3. How often do you upload personal observations within the framework of the Herpmap?

   - One time
   - Varies from time to time
   - Regular yearly a few times
   - Regular monthly
   - Regular weekly
   - Unknown

   If you chose “varies from time to time”, please specify why:....................

4. How has the regularity of your uploads changed over the years?
   - I upload more often than before
   - I upload less often than before
   - The regularity of my uploads has not changed during the years
   - Other, please specify………

5. About which species have you uploaded observations? (You can choose more than one option.)

Amphibians	Reptiles
Fire salamander (*Salamandra salamandra*) Smooth newt (*Lissotriton vulgaris*) Alpine newt (*Ichthyosaura alpestris*) Danube crested newt (*Triturus dobrogicus*) Italian crested newt (*Triturus carnifex*) Agile frog (*Rana dalmatina*) Moor frog (*Rana arvalis*) Common frog (*Rana temporaria*) Marsh frog (*Pelophylax ridibundus*) Pool frog (*Pelophylax lessonae)* Edible frog *(Pelophylax kl. esculentus)* Common treefrog (*Hyla arborea*) Fire-bellied toad (*Bombina bombina)* Yellow-bellied toad (*Bombina variegata)* Common toad (*Bufo bufo)* Green toad (*Bufotes viridis)* Common spadefoot toad (*Pelobates fuscus*) Other amphibian (...)	European adder (*Vipera berus*) Hungarian meadow viper (*Vipera ursinii rakosiensis*) Grass snake (*Natrix natrix*) Dice snake (*Natrix tessellata*) Aesculapian snake (*Zamenis longissimus*) Smooth snake (Coronella austriaca) Caspian whipsnake (*Dolichophis caspius*) European snake-eyed skink (*Ablepharus kitaibelii fitzingeri*) Slow worm (*Anguis fragilis)* Eastern slow worm *(Anguis colhica)* Sand lizard *(Lacerta agilis)* Green lizard *(Lacerta viridis)* Common wall lizard *(Podarcis muralis)* Balkan wall lizard *(Podarcis tauricus)* Viviparous lizard (*Zootoca vivipara)* European pond turtle (*Emys orbicularis)* Red-eared slider (*Trachemys scripta scripta)* Other reptile (...)

B. TECHNOLOGY

6. Which interface did you prefer for uploading your observations?
   - ○ Phone application
   - ○ Home webpage
   - ○ Phone and home webpage equally
   - ○ Other specify ______

7. How often did you visit the following interface during your participation in Herptérkép?

   Scale ranging from 1 to 6: 1 ;Never; 2 A few times in the year; 3 Monthly; 4 Weekly; 5 Daily 6 Irregular

	1	2	3	4	5	6
Herptérkép website	○	○	○	○	○	○
Herptérkép phone application	○	○	○	○	○	○
Herptérkép Facebook	○	○	○	○	○	○

8. How often do you use the below items of the Herptérkép phone **application**? If you haven't used the app, please skip to the next question.
   Scale ranging from 1 to 5: 1 Never; 2 Rarely ; 3 Sometimes; 4 Often; 5 Very often

	1	2	3	4	5
News	○	○	○	○	○
My profile	○	○	○	○	○
Map visualization	○	○	○	○	○
Report an error	○	○	○	○	○
Recording observations	○	○	○	○	○
If there are other menu items that you use often, please enter them!					

9. How often do you use the following menu items of the Herptérkép **website**? If you haven't used the website, please skip to the next question..
   Scale ranging from 1 to 5: 1 Never; 2 Rarely ; 3 Sometimes; 4 Often; 5 Very often?

	1	2	3	4	5
News	○	○	○	○	○
Species information	○	○	○	○	○
Map visualization	○	○	○	○	○
Fieldwork info	○	○	○	○	○
Recording observations	○	○	○	○	○
If there is a menu item not listed that you use frequently, please mention it.					

10. About your experience of using Herptérkép interfaces, indicate your level of agreement according to the following scale ranging from 1 to 5 being:

1 Strongly disagree; 2 disagree; 3 neutral; 4 agree; 5 strongly agree.

	1	2	3	4	5
Uploading my observations through the Herpterkep **website** was understandable and simple	○	○	○	○	○
Uploading my observations through the Herpterkep **phone app** was understandable and simple	○	○	○	○	○
Uploading my observations on the Facebook group was understandable and simple.	○	○	○	○	○
By using the information provided in the app and website I got answers to my questions during my participation in herpterkep.	○	○	○	○	○

11. Which menu items of the Herpterkep phone application didn’t work according to your expectations Please explain why. (You can choose several options.)

		Reason
News	◌	
My profile	◌	
Map visualization	◌	
Report an error	◌	
Recording observations	◌	
Information about data use		
Species descriptions		
None everything functioned as expected	◌	
Other menu item	◌	

Please explain why it didn't work

12. Which menu items of the Herpterkep website didn’t work according to your expectations Please explain why. (You can choose several options.)

		Reason
News	◌	
Species description (Amphibians, Reptiles)	◌	
Map visualization	◌	
Filed work information		
Information about data use r	◌	
Links	◌	
Recording observations		
Information about data use		
None everything functioned as expected	◌	
Other menu item	◌	

Please explain why it didn't work

13. Do you have any suggestions regarding the further development of the phone application?

____

14. Do you have any suggestions regarding the further development of the website?

____

15. Do you have any suggestions regarding the further development of the Facebook page?

C. KNOWLEDGE

16. About amphibians, which of the following knowledgeable groups do you consider you belong to?

- ○ Expert of all species
- ○ Specialist for certain species
- ○ non-expert / amateur

17. About reptiles, which of the following knowledgeable groups do you consider you belong to?

- ○ Expert of all species
- ○ Specialist for certain species
- ○ non-expert / amateur

18. Concerning knowledge acquisition and learning indicate your level of agreement with each statement according to the following scale ranging from 1 to 5:

1 Strongly disagree; 2 disagree; 4 neutral; 4 agree; 5 strongly agree.

	1	2	3	4	5
I feel, that by using the Herptérkép website, my species knowledge increased	○	○	○	○	○
I feel, that by using the Herptérkép phone application, my knowledge of the species has increased	○	○	○	○	○
I feel, that by using the Herptérkép Facebook page, my knowledge of the species has increased	○	○	○	○	○
I feel that my knowledge of the species has expanded through the interaction with the experts of the Herptérkép project.	○	○	○	○	○
Interactivity with other users in the Facebook group has increased my knowledge about reptiles and amphibians.	○	○	○	○	○

Interactivity in the Facebook group has increased my knowledge about the conservation of reptiles and amphibians	○	○	○	○	○
I had sufficient knowledge before participating in Herptérkép, my knowledge didn't change.	○	○	○	○	○
Participating in the Herptérkép project made me realize the importance of my observations.	○	○	○	○	○
I would have liked to receive personal training before starting my participation in the Herptérkép project	○	○	○	○	○
I expanded my knowledge needed to use the Herptérkép with the help of external information sources (e.g. specialist books, other websites, specialist articles, other Facebook groups). Please describe which.	○	○	○	○	○
If you used a form of learning other than the Herptmap, please name it:					

D. MOTIVATION

19. What did motivate you to participate in Herptérkép? Indicate your motivation strength according to the following scale, ranging from 1 to 5

    1 Not at all; 2 disagree; 3 neutral; 4 agree; 5 strongly agree.

	1	2	3	4	5
Recreation/Family activity	○	○	○	○	○
Accomplishing environmental responsibility	○	○	○	○	○
Meeting other people with similar interests in reptiles and amphibians.	○	○	○	○	○
Opportunity to contribute to science	○	○	○	○	○
Personal Interest in amphibians and reptiles	○	○	○	○	○
Learning desire	○	○	○	○	○
Research purposes	○	○	○	○	○
Other (explain)					

20. How did participating in Herptérkép impact your attitude and behavior? Please indicate how much you agree with each statement on a scale of 1-UI to 5 below

    1 Strongly disagree; 2 disagree; 3 neither agree nor disagree; 4 agree; 5 strongly agree.

	1	2	3	4	5
As a result of the project, I minimize the disturbance of amphibians, reptiles, and their environment in the natural environment..	○	○	○	○	○
I share with others my experience in the Herptérkép	○	○	○	○	○

I encourage my family and friends to participate in the Herptérkép project.	◌	◌	◌	◌	◌
My attitude towards nature has not changed. I behaved in a nature-friendly way before participating in the project.	◌	◌	◌	◌	◌

21. What would you suggest to project administrators of Herptérkép to improve participants' experience? Please indicate on a scale of 1 to 5 a

1 is not important at all; 2 disagree; 3 neutral; 4 agree; 5 is very important.

	1	2	3	4	5
Integrate creative elements into project design e.g games, and challenges.	◌	◌	◌	◌	◌
Improve communication channels e.g. Facebook, WhatsApp groups	◌	◌	◌	◌	◌
Improve the feedback about my observations	◌	◌	◌	◌	◌
More activities encourage interaction between participants and scientists.	◌	◌	◌	◌	◌
Include participants in more stages of the project	◌	◌	◌	◌	◌
If you have any other suggestions, please let us know!					

22. How would you rate the overall value of your experience participating in herpterkep?

5 Excellent
4 Very good
3 Medium
2 Acceptable
1 Less than acceptable

23. How likely are you to keep participating in the Herptérkép?

◌ 5 Very likely

◌ 4 Likely

◌ 3 PossiblyI wont

◌ 2 Not Likely

◌ 1 Unikely / Definitely I won’t

24. If you are not planning to continue participating in the Herptérkép, please let us know why:

____

E. DEMOGRAPHIC QUESTIONS

25. In which town/city do you live?

____

26. Which gender do you identify with?

- Male
- Female
- Prefer not to say

27. How old are you?

18-29
30-39
40-49
50-59
60 +

28. What is your highest level of education attended?

- Elementary
- Technical
- Higher education
- Other (please specify) ____________________

29. Are you a member of any kind of conservation organization?

- No
- Yes (specify)_________

30. Are you involved in an additional environmental/social/communal activity in addition to the herpterkep?

- No
- Yes (please specify) ____________________

31. Is your educational institution or workplace related to nature conservation?

- No
- Yes (specify)_________

If you have any other comments or suggestions, please share them with us.

Thank you for providing us with valuable insights and time to fill out the survey.

Questionnaire for participants of WildWatcher

Dear participants of the Vadonleső citizen science project, welcome to our survey! We invite you to take part in the survey which will take you appr. 20 minutes to complete.

Information on the research

The questionnaire is part of a Ph.D. research on conservation-related citizen science conducted in collaboration with MME. It aims to assist the further development of the citizen science project Vadonleső.

We refer to Citizen Science as the participation of non-scientists in one or more stages of scientific research to produce new knowledge it will be useful for scientific and conservation purposes.

Data protection

The data of the questionnaires are treated confidentially in accordance with the ethical principles of the Code of Scientific Ethics of the Hungarian Academy of Sciences and the European Code of Conduct for Research Integrity, and in accordance with the rules of the EU GDPR. The analysis is anonymous and only aggregated data is disclosed. Participation in the survey is voluntary

By checking the box below, you indicate that you have read the information, below and consent to participate in the ECSP survey prepared by Johanna Soria and the Herpterkep team of MME

○ Consent

Thanks for participating.

A. GENERAL INFORMATION ABOUT THE PARTICIPATION

1. Through which channel did you hear first about Vadonleső? (You can choose more than one option)
    - Nature conservation organization
    - Social Media
    - TV, radio
    - Newspaper
    - Friends
    - Other (please specify) ____________________

2. How many years have you been involved in the project?

______

3. How often do you upload/upload observations within the framework of Vadonleső?

- ○ One time
- ○ Varies from time to time
- ○ Regular yearly a few times
- ○ Regular monthly
- ○ Regular weekly
- ○ Unknown

If you chose “varies from time to time”, please specify why:....................

4. How has the frequency of your uploads changed over the years?

- ○ I upload more often than before
- ○ I upload less often than before
- ○ The regularity of my uploads has not changed during the years
- ○ Other, please specify………

5. About which species have you uploaded observations? (You can choose more than one option.)

növények

Check all that apply.

- ☐ Fehér tündérrózsa (Nymphaea alba)
- ☐ Hóvirág (Galanthus nivalis)
- ☐ Leánykökörcsin (Pulsatilla grandis)
- ☐ Szúrós csodabogyó (Ruscus aculeatus)
- ☐ Tavaszi hérics (Adonis vernalis)
- ☐ Kornistárnics (Gentiana pneumonanthe)
- ☐ Turbánliliom (Lilium martagon)
- ☐ Other: ______

állatok *

Check all that apply.

- ☐ Keleti sün (Erinaceus roumanicus)
- ☐ Mókus (Sciurus vulgaris)
- ☐ Ürge (Spermophilus citellus)
- ☐ Vakond (Talpa europaea)
- ☐ Foltos szalamandra (Salamandra salamandra)
- ☐ Zöld levelibéka (Hyla arborea)
- ☐ Mocsári teknős (Emys orbicularis)
- ☐ Imádkozó sáska (Mantis religiosa)
- ☐ Nagy szarvasbogár (Lucanus cervus)
- ☐ Nappali pávaszem (Nymphalis io)
- ☐ Denevérek (Chiroptera)
- ☐ Other: ______

B. TECHNOLOGY

6. Which interface did you prefer to upload your observations?

- ◌ Phone application
- ◌ Home webpage
- ◌ Phone and home webpage equally
- ◌ Other specify _______

7. How often did you visit the following interface during your participation in Vadonleső?

   Scale ranging from 1 to 6: 1 ;Never; 2 A few times in the year; 3 Monthly; 4 Weekly; 5 Daily 6 Irregular

	1	2	3	4	5	6
Vadonleső website	◌	◌	◌	◌	◌	◌
Vadonleső phone application	◌	◌	◌	◌	◌	◌

8. How often do you use the following items of the Vadonleső phone **application**? If you haven't used the app, please skip to the next question.
   Scale ranging from 1 to 5: 1 Never; 2 Rarely ; 3 Sometimes; 4 Often; 5 Very often

	1	2	3	4	5
My profile	◌	◌	◌	◌	◌
Map visualization	◌	◌	◌	◌	◌
Contact center	◌	◌	◌	◌	◌
If there are other menu items that you use often, please enter them!					

9. How often do you use the following menu items of the Vadonleső **website**? If you haven't used the website, please skip to the next question..
   Scale ranging from 1 to 5: 1 Never; 2 Rarely ; 3 Sometimes; 4 Often; 5 Very often?

	1	2	3	4	5
Species information	◌	◌	◌	◌	◌
Mammal of the year	◌	◌	◌	◌	◌

Contributions	○	○	○	○	○
Games	○	○	○	○	○
Downloadable materials	○	○	○	○	○
Map Visualization					
Numbers and Statistics					
Report an observation					
If there is a menu item not listed that you use frequently, please mention it.					

10. About your experience of using Vadonleső interfaces, indicate your level of agreement according to the following scale ranging from 1 to 5 being:

1 Strongly disagree; 2 disagree; 3 neutral; 4 agree; 5 strongly agree.

	1	2	3	4	5
Uploading my observations through the Vadonleső **website** was understandable and simple	○	○	○	○	○
Uploading my observations through the Vadonleső **phone app** was understandable and simple	○	○	○	○	○
With the help of the phone application and/or the information on the website, I received answers to my questions during the participation in the Wilderness project.	○	○	○	○	○

11. Which menu items of the Herpterkep phone application didn't work according to your expectations Please explain why. (You can choose several options.)

		Reason
My profile	◌	
Map visualization	◌	
Contact center	◌	
None, everything worked as expected.	◌	
I don't use the app.	◌	

Please explain why it didn't work

12. Which menu items of the Herpterkep website didn't work according to your expectations Please explain why. (You can choose several options.)

		Reason
Species information	◌	
Mammal of the year	◌	
Contributions	◌	
Games		
Downloadable materials	◌	
Map Visualization	◌	
Numbers and Statistics		
Report an observation		
None everything functioned as expected	◌	
Other menu item	◌	

Please explain why it didn't work

13. Do you have any suggestions regarding the further development of the phone application?____

14. Do you have any suggestions regarding the further development of the website?

____

C. KNOWLEDGE

15. When it comes to plants expertise, which of the following groups do you think you belong to?

○ Expert of all species

○ Specialist for certain species

○ non-expert / amateur

16. Regarding animals, which of the following groups do you consider yourself to belong to?

○ Expert of all species

○ Specialist for certain species

○ non-expert / amateur

18. Concerning knowledge acquisition and learning indicate your level of agreement with each statement according to the following scale ranging from 1 to 5:

1 Strongly disagree; 2 disagree; 4 neutral; 4 agree; 5 strongly agree.

	1	2	3	4	5
I feel, that by using the Vadonleső website, my species knowledge increased	○	○	○	○	○
I feel, that by using the Vadonleső phone application, my knowledge of the species has increased	○	○	○	○	○
[I feel that my knowledge of the species has been expanded through the interaction with the experts of the Wilderness program	○	○	○	○	○

I had sufficient knowledge before participating in Vadonleső, my knowledge has not changed	○	○	○	○	○
Participating in the Wilderness Program made me realize the importance of my observations.	○	○	○	○	○
I would have been happy to receive personal training before starting my participation in the Wilderness program	○	○	○	○	○
If you used a form of learning other than the Vadonleso, please name it:					

D. MOTIVATION /ATTITUDE/ BEHAVIOR

19. What did motivate you to participate in Vadonleső? Indicate your motivation strength according to the following scale, ranging from 1 to 5

1 Not at all; 2 disagree; 3 neutral; 4 agree; 5 strongly agree.

	1	2	3	4	5
Recreation/Family activity	○	○	○	○	○
My responsibility towards nature	○	○	○	○	○
Meet other people with a similar interest in animals and plants	○	○	○	○	○
Personal interest in plants and animals	○	○	○	○	○
Desire to learn	○	○	○	○	○
Research objectives	○	○	○	○	○
Great game, great fun	○	○	○	○	○

20. How did participating in Vadonleső impact your attitude and behavior? Please indicate how much you agree with each statement on a scale of 1-UI to 5 below

1 Strongly disagree; 2 disagree; 3 neither agree nor disagree; 4 agree; 5 strongly agree.

	1	2	3	4	5
As a result of the program, I minimize the disturbance of animals, plants and their environment in the natural environment.	○	○	○	○	○
I share with others my experience in the Vadonleső	○	○	○	○	○
I encourage my family and friends to participate in the Vadonleső project.	○	○	○	○	○
My attitude towards nature has not changed. I behaved in a nature-friendly before participating in the project.	○	○	○	○	○

21. What would you suggest to project administrators of Vadonleső to improve participants' experience? Please indicate on a scale of 1 to 5 a

1 Strongly disagree; 2 disagree; 3 neither agree nor disagree; 4 agree; 5 strongly agree.

	1	2	3	4	5
Incorporation of creative elements into the program, e.g. more games and challenges	○	○	○	○	○
Improve communication channels e.g. Facebook, WhatsApp groups	○	○	○	○	○
Improve the feedback about my observations	○	○	○	○	○
More activities encourage interaction between participants and scientists.	○	○	○	○	○
Include participants in more stages of the project	○	○	○	○	○
If you have any other suggestions, please let us know!					

22. How would you rate the overall value of your experience participating in Vadonleso?

5 Excellent
4 Very good
3 Medium
2 Acceptable
1 Less than acceptable

23. How likely are you to keep participating in the Vadonleső?

- 5 Very likely
- 4 Likely
- 3 Neutral
- 2 Not Likely
- 1 Unlikely / Definitely I won't

24. If you are not planning to continue participating in the Vadonleső, please let us know why:

____

E. DEMOGRAPHIC QUESTIONS

25. In which town/city do you live?

____

26. Which gender do you identify with?

- Male
- Female
- Prefer not to say

27. How old are you?
18-30
31-40
41-50
51-60
Over 60

28. What is your highest level of education attended?

- Primary
- Secondary
- Higher education

29. Are you a member of any kind of conservation organization?

- No
- Yes (specify)________

30. Are you involved in an additional environmental/social/communal activity in addition to the herpterkep?

- No
- Yes (please specify) ____________________

31. Is your educational institution or workplace related to nature conservation?

- No
- Yes (specify)________

If you have any other comments or suggestions, please share them with us.

Thank you for providing us with valuable insights and time to fill out the survey.

9.3. Appendix 3. Target species of WildWatcher

Table 17. Number of species per taxonomic class in WildWatcher

Species	**Class**								**Total**
	Mammal	Reptile		Amphibian		Insect	Liliopsida	Magnoliopsida	
	WildWatcher	Amphibian and Reptile Mapping	WildWatcher	Amphibian and Reptile Mapping	WildWatcher	WildWatcher	WildWatcher	WildWatcher	
Ablepharus kitaibelii		518							518
Adonis vernalis								909	909
Anguis colhica		314							314
Anguis fragilis		1309							1309
Bombina bombina				4725					4725
Bombina variegata				781					781
Bufo bufo				5530					5530
Bufotes viridis				2685					2685
Chiroptera	457								457
Coronella austriaca		998							998
Dolichophis caspius		615							615
Emys orbicularis		5386	587						5973
Erinaceus roumanicus	3800								3800
Euplagia quadripunctaria						121			121
Galanthus nivalis							471		471
Gentiana pneumonanthe								21	21
Hyla arborea				3114	575				3689
Ichthyosaura alpestris				339					339
Lacerta agilis		3191							3191
Lacerta viridis		6530							6530
Lilium martagon							54		54
Lissotriton vulgaris				1506					1506
Lucanus cervus						1881			1881
Mantis religiosa						1109			1109

Species	**Class**								**Total**
	Mammal	Reptile		Amphibian		Insect	Liliopsida	Magnoliopsida	
Mustela erminea	181								181
Natrix natrix		2629							2629
Natrix tessellata		1135							1135
Nymphaea alba								177	177
Nymphalis io						205			205
Other amphibian				3					3
Other reptiles		115							115
Pelobates fuscus				6877					6877
Pelophylax kl. esculentus				5428					5428
Pelophylax lessonae				263					263
Pelophylax ridibundus				1616					1616
Podarcis muralis		3034							3034
Podarcis tauricus		489							489
Pulsatilla grandis								397	397
Rana arvalis				746					746
Rana dalmatina				6589					6589
Rana temporaria				1074					1074
Ruscus aculeatus							108		108
Salamandra salamandra				2520	792				3312
Sciurus vulgaris	2656								2656
Spermophilus citellus	351								351
Talpa europaea	2454								2454
Trachemys scripta elegans		826							826
Triturus carnifex				43					43
Triturus dobrogicus				1343					1343
Vipera berus		772							772
Vipera ursinii rakosiensis		2							2
Zamenis longissimus		1126							1126
Zerynthia polyxena						178			178
Zootoca vivipara		244							244
	9899	29233	587	45182	1367	3494	633	1504	91899