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WET HORIZONS

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D7.7 Citizen Engagement Guidelines

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1 PU = Public
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Acronyms and abbreviations

Abbreviation	Description
DSS	Decision Support System
CS	Citizen Science
EU	European Union
RRI	Responsible Research and Innovation
SDG	Sustainable Development Goal(s)
CORDIS	Community Research and Development Information Service
ECSA	European Citizen Science Association
ILK	Indigenous and Local Knowledge
CBM	Community-Based Monitoring

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Executive Summary

Citizen science is simultaneously a scientific research practice that harks back to the days where it was common for amateur scientists to be heavily involved in scientific process and an emerging tool for conducting scientific research whilst engaging the public, improving scientific literacy, and democratising research agendas. The increasing attention citizen science has been given as a way of engaging the public in science is one notable shift in the trajectory of the field over past decades.

Wetlands, as ecosystems that are often misunderstood and underappreciated, as well ones with immense ecosystem value from provisioning services to cultural services, are ideal focuses for citizen science research. This report reviews the current state of citizen science research, including ongoing contention topics such as defining the term and evaluating its impact and potential. Using this literature review, a guideline was developed that makes a first step towards a wetland-specific citizen science framework.

Evaluating the use of citizen science under a threefold metric: (1) accessibility for non-scientists, (2) scientific robustness, and (3) outreach and awareness potential, this report shows that citizen science has the potential to fulfil these under the caveat that research design and project articulation are key. As such this report contributes to the ongoing research on citizen science, and specifically to a lesser-studied subsection, that of citizen science *and* wetlands.

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1 Introduction

1.1 Project introduction

This task is a component of WET HORIZONS, a Horizon Europe project that aims to provide a key starting point from which to address the challenge of enhancing wetland restoration using a holistic approach. It will boost crucial wetland knowledge and help us develop sound tools and approaches to fast-track large-scale restoration action.

Despite the efforts of previous projects that have addressed wetlands restoration, there remain important knowledge gaps due to a lack of wetland data availability and harmonisation of the existing information. This project will improve the current data from pristine, drained and rewetted peatlands, floodplains and coastal wetlands; model the effects of typical restoration measures under variable conditions; and analyse the potential socioeconomic impacts of such measures. This will enable us to choose the best pathways in wetland restoration, minimising trade-offs, including hotspot priority lists where the ecological and biodiversity benefits are greatest with minimum investment.

The WET HORIZONS project will involve citizen science for data collection and will include the development of digital tools for upscaling wetland restoration, including an app for the visualisation of wetland status and a decision support system (DSS) for policymakers. The results will be available through open-access repositories to maximise their use and outreach. Figure 1 highlights the connections among the main project phases and components.

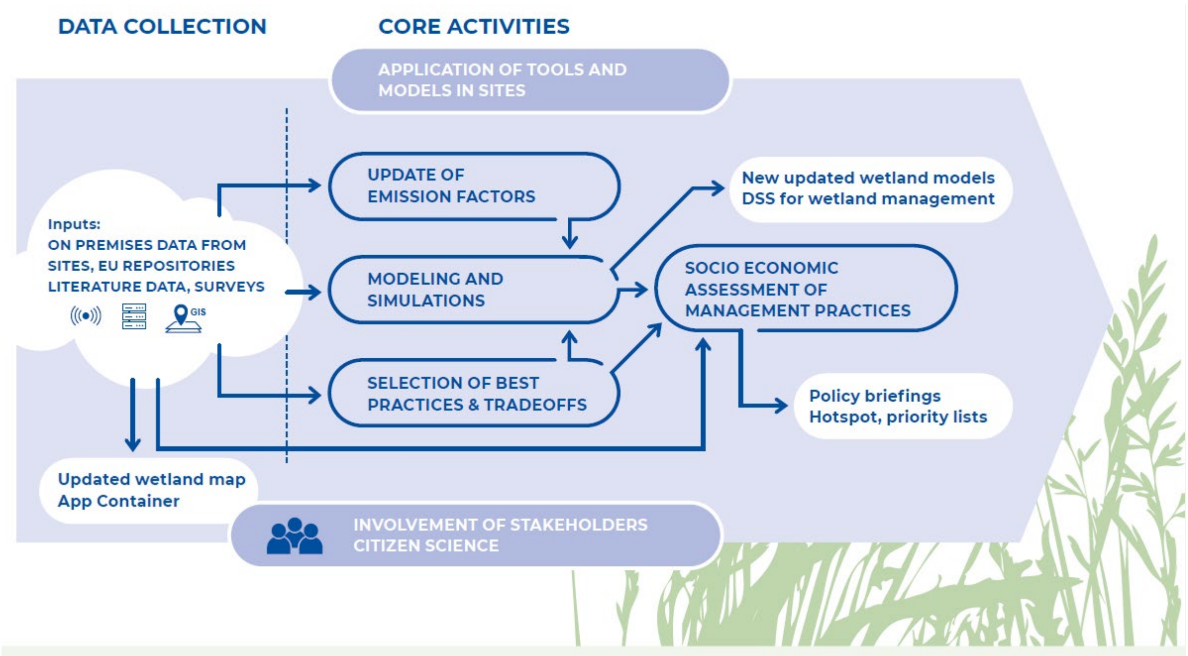

Figure 1: Explanatory diagram of main project components and relations among core activities and outputs.

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1.2 Citizen Science

Citizen science (CS), whereby the general public plays a key role in scientific research, is rapidly gaining traction and being recognised as a valuable approach to robust environmental management (McInnes et al., 2020), tackling research questions that require large datasets and engaging the public in the scientific process (Miller-Rushing et al., 2012). Amongst those recognising the value of CS are policy makers, funding institutions, and scientific researchers (Brouwer et al., 2019). Although CS projects may show considerable variation (e.g., in scope and discipline), they tend to share several common elements, such as public participation, scientific research outputs, and a political or social dimension (Skarlatidou and Haklay, 2021). The present report investigates the state of CS usage for wetland ecosystems, with a focus on European wetlands, using a thematic literature review and a state-of-the-art review that assesses CS projects in the EU and tools used for wetland assessment. This assessment is then used to create guidelines for CS engagement in wetland research and restoration activities. The guideline considers the accessibility of particular tools and methods for non-scientists and their suitability for scientific purposes. It also considers people's perceptions – both that of participants and scientists – and their motivation to be involved and use CS. The capacity of CS to act as an outreach and engagement tool, including civic empowerment and policy possibilities, are also considered. The guideline intends to capture all three of these aspects: accessibility for non-scientists, scientific robustness, and outreach potential, both building on previous work in this field and contributing to the discourse.

Research demonstrates that CS has the ability to serve multiple purposes and achieve a variety of outcomes simultaneously (Kobori et al., 2016). Indeed, this ability to provide opportunities for scientific inquiry alongside opportunities to learn about environmental issues and get involved in societally relevant processes has been listed by some authors as a unique feature of citizen science (Turrini et al., 2018). This is a strength recognised by the European Union (EU) as well, evidenced by its inclusion in the EU's Responsible Research and Innovation (RRI) methods, which emphasise that societal challenges should be a primary focus of scientific research. The incorporation of CS in the RRI reflects the EU's acknowledgement of the need for public engagement with science and contributes to the shared responsibility between science, public, and society envisaged by the RRI (Skarlatidou and Haklay, 2021). In 2020, the EU launched a central platform for CS, called "EU-Citizen.Science", which is designed to be the reference point for participants, practitioners, researchers, policymakers, and society, gathering best practices for initiating, planning, and executing CS projects (Directorate-General for Research and Innovation, 2020). In addition, there are a number of citizen science projects funded by the EU, including those pertaining to wetlands.

Wetlands, covering approximately 6% of the world's land surface (Erwin, 2009) and 5% of Europe (Junk et al., 2013), are important for a myriad of reasons, including for their carbon sequestration potential, biodiversity hosting, flood buffering and protection, and water purification and freshwater provisioning. The wealth of ecosystem services they provide is disproportionately large given their relatively lesser presence in the landscape (Murry, 2019). Their conservation and wise use are vital for human livelihoods (Ramsar Convention on Wetlands (hereafter Ramsar), 2018). With the effects of climate change increasing, wetlands are more critical than ever for achieving sustainable development;

they contribute, directly or indirectly, to 75 Sustainable Development (SDG) indicators (Ramsar, 2018). Conversely, climate change presents a serious risk to wetlands, across a number of fronts, such as changing temperature and precipitation regimes shifting the balance of carbon cycling, causing wetlands to become carbon sources, or combining with other drivers such as invasive species, leading to biophysical changes. In order to counter the multiple challenges facing wetlands, which in turn have serious implication for all of society, Ramsar (2018) outlines several key responses: institutional and governance, management, investment, and knowledge.

Studying large-scale patterns in nature requires extensive data inputs, with wetlands being no different. The vast amount of data that may be collected is one of the major strengths of CS (Bonney et al., 2009, Miller-Rushing et al., 2012). There is not currently a thorough understanding of how direct and indirect drivers[1] and global trends lead to wetland loss and degradation, due to the complex nature of these phenomena (Ramsar, 2018). Multiple authors (e.g., McInnes et al., 2020; Spatharioti et al., 2021) have drawn attention to the lack of information available on the state and trends of remaining wetlands. Ramsar stresses the need for improved national wetland inventories and wetland extent tracking, which support the urgent action needed at national and national levels (2018).

Therefore, in acknowledgement of the vital role of wetlands and the present challenges facing wetlands in terms of both restoration and reputation, this report offers recommendations for citizen science-wetland guidelines.

2 Methodology

The development of this guideline utilised a mixed methods review, consisting of a literature review and a state-of-the-art review. The latter of these includes an inventory of EU projects using CS and the existing wetland research tools. This approach is designed to provide comprehensive understanding of CS with the literature review providing extensive insight into the field including definition, contribution, challenges, and status, while the state-of-the-art review describes the current trends, usage, and tools. This lays the foundation for a robust guideline that fulfils the goals of being accessible, scientifically sound, and valuable for outreach purposes. The chapter details each of these methods in the research design section before mentioning some limitations of the methodology and providing a summary.

2.1 Literature review

The literature review includes both peer reviewed literature and non-peer reviewed publications. Non-peer reviewed reports and documentation have been included on account of many CS projects not presently resulting in scientific publications (Kullenberg and Kasperowski, 2016). These sources were analysed for their description of citizen science both broadly and as pertaining to specific case studies,

[1] According to Ramsar, direct drivers are natural or anthropogenic causes of biophysical changes as a local and regional scale, while indirect drivers have a broader and more diffuse effect (mostly by influencing direct drivers) and often relate to institutional, socio-economic, demographic, and cultural processes (Ramsar, 2018).

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with specific attention given to those that relate to wetlands. However, CS projects that looked at other environmental phenomena were also assessed. For peer reviewed literature, both Google Scholar and ScienceDirect engines were utilised, while Google Scholar and the regular Google search engine provided sources for non-peer reviewed publications. Authors (i.e., de Vries et al., 2017) have commented on their use of e.g., Web of Science to search for academic papers as it has less noise than Google Scholar. In this report, however, Google Scholar was used in order to broaden the results received and ensure that technical guidelines and other such uses of CS were included. ScienceDirect was used to ensure that a representative impression of the current scope and extent of CS peer-reviewed literature was demonstrated. For both search engines, the sourcing of relevant articles was done systematically using the terms, sequentially: “citizen science”, “wetlands” AND “citizen science”, "wetlands" AND "citizen science" AND "biodiversity", "wetlands" AND "citizen science" AND "GHG” and "wetlands" AND "citizen science" AND "GHG" AND "biodiversity". The references of the chosen articles were then also assessed, with the relevant papers being further analysed.

2.2 State-of-the-art review

This report used a state-of-the-art review to reflect the present state of CS development. There are two components to this: an assessment of EU projects involving CS and an analysis of existing wetland research tools that have been or have the potential to be used for CS.

I. To assess the current state of CS within the EU, this report also included an **inventory of EU projects**. This includes projects that use CS directly or are related to CS in some way. The inventory uses the European Commission site, CORDIS (the Community Research and Development Information Service), which is the primary source of project results funded from the EU’s framework programmes for research and innovation (European Commission, n.d.). The search terms “citizen science” and "wetlands" AND "citizen science" are used to filter the projects.

II. To gain an insight into how CS may be used for wetland research, an assessment of **existing wetland research tools** is conducted, with particular attention paid to those that are either currently being used for CS or have the potential to be used in this way. This section of the methodology connects to the literature review above, with the tools mentioned in those papers and reports being investigated further. Additionally, targeted searching of tools that may match both CS requirements and suitability for wetland environments was conducted. Two key aspects of wetland research are biodiversity and biogeochemical indicators, which require different approaches and tools. The possibilities for both of these indicators are considered.

3 Results

3.1 Literature Review

3.1.1 Appearance within the literature

The quantity of studies yielded by the present report according to designation may be found in Fig. 2. As seen in this image, there are two major diverging qualifications: (1) between the search engines, either ScienceDirect or Google Scholar, and (2) between search of “biodiversity” and “greenhouse gas”. Google Scholar contains substantially more results than ScienceDirect, which is likely due to the inclusion of so-called grey literature such as conference proceedings and other non-peer reviewed material and articles related to those searched for. The most relevant articles were chosen from either search engine to be included in this report, with the total results yielding providing an insight into the status of citizen science as a field of study. This is underlined by the fact that when searching for both “biodiversity” AND “greenhouse gas” there is only a small decrease from only “greenhouse gas” searches. The difference between the number of results available for “biodiversity” versus “greenhouse gas” is likely due to biodiversity research lending itself better to use in citizen science, with the equipment and knowledge level required for testing GHGs being more costly and advanced.

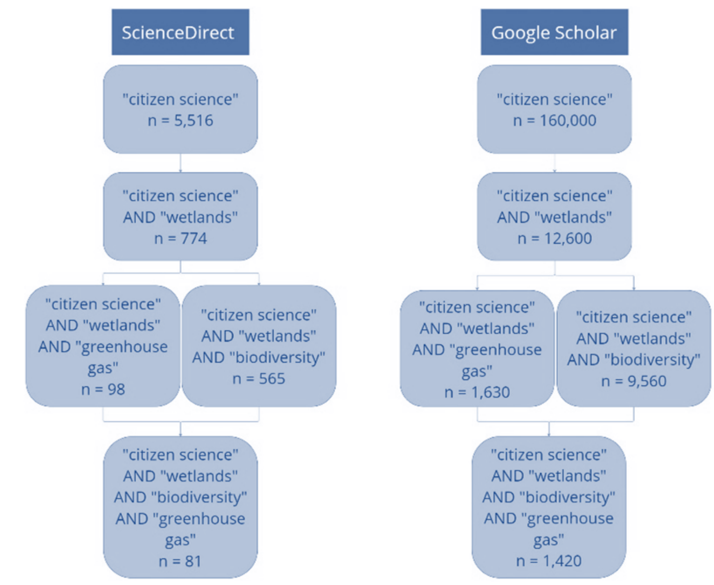

Figure 2: Tree diagram of results yielded by literature review per search engine (note: results taken from a final search conducted on the 29-May 2023)

3.1.2 Citizen Science Definition

There exist various definitions and interpretations of CS (Pocock et al., 2014) with the definition of both CS and a ‘citizen scientist’ still being debated (McInnes et al., 2020; Haklay, 2013; Bonney et al., 2016). Indeed, Haklay et al. (2021) provide an overview of 35 definitions from organisations and institutions such as the Oxford English Dictionary, ECSA, UNESCO, the EU, and Science Europe.

Robinson et al. (2018) identify one of the challenges of CS being cohesion and identifying a global common purpose. In 2015 the European Citizen Science Association (ECSA) outlined Ten Principles of Citizen Science (ECSA, 2015) with the intention that they could be applied irrespective of academic discipline or cultural context (Box 3.1). Some authors caution that there are many caveats to these principles so they should not be understood as a replacement for a clearer description of a CS project that fits into a specific context (Haklay, 2021, in Newby, 2022).

Box 3.1: ECSA Ten Principles of Citizen Science (ESCA, 2015)

I. Citizen science projects' activity involve citizens in scientific endeavours that generate new knowledge or understanding. Citizens may act as contributors, collaborators, or as project leader and have a meaningful role in the project.

II. Citizen science projects have a genuine science outcome. For example, answering a research question or informing conservation action, management decisions or environmental policy.

III. Both the professional scientists and the citizen scientists benefit from taking part. Benefits may include the publication of research outputs, learning opportunities, personal enjoyment, social benefits, satisfaction through contributing to scientific evidence, e.g., to address local, national, and international issues, and through that, the potential to influence policy.

IV. Citizen scientists may, if they wish, participate in multiple stages of the scientific process. This may include developing the research question, designing the method, gathering, and analysing data, and communicating the results.

V. Citizen scientists receive feedback from the project. For example, how their data are being used and what the research, policy or societal outcomes are.

VI. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for. However, unlike traditional research approaches citizen science provides opportunity for greater public engagement and democratisation of science.

VII. Citizen science project data and meta-data are made publicly available and, where possible, results are published in an open access format. Data sharing may occur during or after the project unless there are security or privacy concerns that prevent this.

VIII. Citizen scientists are acknowledged in project results and publications.

IX. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.

X. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.

The definition used in this report builds on the definition used in Brouwer et al. (2019), which in turn follows the work from Brouwer et al. (2018), Bonney et al. (2009), Shirk et al., (2012), and ca et al., (2014). The authors define CS as "*any form of active public participation in research processes set up to generate science-based knowledge*" (Brouwer et al., 2019). This definition is utilised as it permits volunteers, experts, and paid participation, it incorporates different forms of engagement (i.e., asking research questions, collecting data, analysing and disseminating results), and it explicitly looks towards scientifically valuable output. As this guideline pertain specifically to wetlands, specificities of these ecosystems are incorporated into the definition of the present report.

Therefore, we used the definition:

"Citizen science is any form of active public participation in wetland research processes set up to generate science-based knowledge and understanding of wetland ecosystems, with an intention to restore and maintain wetlands."

3.1.3 Impact and Potential

Citizen science has made sizeable contributions to a number of scientific disciplines and has particularly been pursued in conservation (McInnes et al., 2020; McKinley et al., 2017) and ecological science (Kobori et al. 2016; Turrini et al., 2018; Fraisl et al., 2022). The precursors to citizen science – with the same objectives and formulations but not the term – have long contributed to scientific understanding (Miller-Rushing et al., 2012). Keen amateurs and volunteers conducted scientific research in the days before science emerged as a profession, making some key contributions (McKinley, 2017); the true extent of this contribution is still being evaluated with historical datasets being revisited (Miller-Rushing et al., 2012). One of the major fields where this can be seen is ornithology, where amateurs continue to contribute in a significant way, beyond that of a majority of disciplines (Greenwood, 2007). Their influence has been felt, in the UK at least, in ringing schemes, a national bird census and atlas project (Greenwood, 2007). The popularity of citizen science in the ornithological field, or in the alternative phrasing, the influence of ornithology on citizen science may be seen in the extensive databases and programmes that combine these two. This includes eBird (global), BirdTrack (UK), the Swedish Bird Survey, the International Waterbird Census, and the Big Garden Birdwatch (UK). CLO is a particularly involved actor in the CS for bird observations with hundreds of thousands of people contributing. This data is used by scientists for a range of purposes while the projects themselves are diverse as well (from eBird that operates anywhere at any time, to locally embedded urban bird and bird nest projects. Other major fields where the role of citizen scientists has remained prevalent is in archaeology, where they frequently join excavations, or astronomy, where observations and identifications from citizens have been on par with scientists (Haklay, 2013).

Pocock et al. (2018) have identified citizen science as having a twofold role, focusing particularly on how these relate to international agreements. The first of these is related to the generation of scientifically robust data which may be used for environmental monitoring and assessing progress of environmental targets (Pocock et al., 2018). The second role regards the social and cultural implications of citizen science, including an increase in social capital, awareness, empowerment, and action as a result of individuals participating in citizen science ventures (Pocock et al., 2018). Turrini et al. (2018) expand the second role identified by Pocock et al., categorising learning opportunities and civic participation as separate roles, alongside knowledge generation (Fig.1 in Turrini et al., 2018). Seymour et al. (2022) likewise emphasise the role of citizen science in civic participation as a means of linking science and society, while Turrini et al. (2018) include the link to policy as well. There has been discussion over the past years regarding the potential of CS to democratise research. CS creates a space where different behaviours, intentions, interrelations, agenda, and interests can be brought together, through which political processes may be influenced (Newby, 2022). It is suggested that CS may improve scientific literacy amongst the public and contribute to making science more democratic (Toomey, 2014); this can be in terms of inclusiveness and a better alignment of science with societal needs (Brouwer et al., 2019) and community concerns (Newby, 2022). Indeed, citizen science may be understood as a bridge between the public and environmental governance processes, which offers the possibility to tackle equity and sustainability issues and incorporate social justice and responsibility (Newby, 2022). Furthermore, CS is seen as a means of supporting and exploring different dimensions of Indigenous peoples and community well-being, customary governance, [traditional] ecological knowledge, natural resource use, and other types of interaction between people and surroundings (Chiaravalloti et al., 2021); it has even been described as a conduit for Indigenous and local knowledge (ILK) in ecosystem stewardship and conservation (Tengö et al., 2021).

In summary, the benefits of CS are manifold. The broad capacities of CS should be recognised without comparing it constantly with 'regular' science; Liboiron (2019) argues that CS offers the chance to do more accountable, collective, community-oriented, accessible, and equitable science. Pocock et al. (2014) offer a useful summary of how this may play out in their list of advantages, which include the following:

I. People may become (more) engaged with important issues;
II. The public gains a fuller understanding of the complexity and challenges regarding these issues, through, e.g., the handing of data;
III. A deeper sense of trust in organisation may be fostered;
IV. A more cost-efficient manner of conducting research, particularly at large spatio-temporal extents and fine spatio-temporal resolutions;
V. Recruitment of committed volunteers may be a more reliable way of gathering data in long-term projects as they are less subject to the whims of funding agencies;
VI. More simultaneous monitoring may be permitted;
VII. In some cases, expert amateurs have superior skills than professionals.

Despite these noted benefits of CS, there remain plenty of spaces for improvement in terms of the amount of impact it is able to have. This includes its contribution to decision-making and socio-ecological resilience which empirical reviews have shown to be trivial (Newman et al., 2017). There is a recognised potential here so the barriers to its use in decision-making ned to be better understood (Newman et al., 2017).

3.1.4 Challenges

Despite CS-based survey and monitoring being increasingly recognised as a reliable and valuable component of ecological monitoring (McInnes et al., 2020), there remain a number of barriers in place that prevent CS from being taken up as a method. Burgess et al. (2017), in the context of biodiversity CS projects, identified four general barriers:

I. A limited awareness amongst scientists of CS projects that may match their needs;
II. Not all biodiversity science being well-suited for CS;
III. Inconsistency in data quality across projects, and;
IV. Bias amongst scientists for certain data sources (i.e., published via particular institutions and age or education level of data collectors).

The fact that there is a lack of understanding amongst scientists (1) about how CS may be used in their projects is related to another issue raised in the literature, which is that of projects conceptualised and in motion without any input from scientists. Greenwood refers to this as a "misuse of the phrase" (2007, p.78), whereby the term CS is used to cover projects that have no scientific value. These are projects which are designed for purposes outside of scientific results, such as awareness of environmental issues or member recruitment, but are promoted as research projects to the public (Greenwood, 2007). The author argues that this type of promotion devalues CS in the eyes of the participants and wider public (Greenwood, 2007). In comparison to this, Salmon et al. (2021) came to consider a project they initially deemed not a CS project to be one due to the fact that the participants and public considered it to be CS. Ultimately, this demonstrates the challenges present in CS at the present moment without a fixed definition as well as longer term challenges that exist with a tool that has many moving parts and contextual applications.

CS is in many ways still developing as an approach; it is also quite unconventional, meaning it raises new questions that need time and effort to broach. Science and society have historically been seen as separate entities, whereas with CS, these boundaries between scientific and civic actors start to blur (Shirk and Bonney, 2015). This may cause tension, conflict, or simply be challenging for professional scientists, which in turn can pose a challenge for the field to navigate. Furthermore, it requires careful attention to the various stages and needs. For instance, communication is a crucial element of CS, wherein the members of the public are no longer an external audience, nor are they party to the scholarly communication within the academic community but are part of the project itself (Shirk and Bonney, 2015). This changes the mode of communication from e.g., a science festival (Shirk and Bonney, 2015), to another mode with new requirements and standards.

The question of bias remains one of the most dominant critiques of CS. There is much mention in the literature of ways of reducing the presence and risk of bias (Pocock et al., 2014; Brouwer et al., 2019; Fraisl et al., 2022). Taking this further, Haklay (2013) challenges the underlying assumption present in the bias discourse. The author argues that the mistrust of CS in this way is based on the view that science is best left to scientists and that it requires the rigour, knowledge and skills that are only developed by professional scientists with time (Haklay, 2013). This notion is what Haklay (2013) contends leads to the suspicions, derision, and dismissal of CS as a valuable method of scientific research. Although science is usually seen as the progenitor of the most rigorous and accurate evidence to inform decision-making, in many areas across the world, ecosystems are governed primarily by Indigenous peoples and local community, which CS is seen as one means for this to be incorporated to a greater extent (Tengö et al., 2021). Analogous to the suspicion scientists have of CS, there is also suspicion on the part of the public, who may distrust scientists, believing them to be responsible for harmful technologies (i.e., pesticides) (Greenwood, 2007). Once again, these discussions point to the emergent field of CS, with time needed to build these levels of trust on the part of the public towards scientists and the scientific field more broadly and scientists towards the general public and their ability to conduct sound science.

3.2 State-of-the-art Review

3.2.1 EU projects involving Citizen Science

On the CORDIS platform, a search for “citizen science” yielded 1257 results while "wetlands" AND "citizen science" yielded 29 results. This included multiple mentions from certain projects. A summary of the relevant EU projects utilising or mentioning citizen science and wetlands is given in Table 1. The EU projects using CS have been categorised according to the following groupings:

I. Integral: these projects have CS at their heart. The project is either directly investigating CS in various forms or has CS has a key component of a wider methodology. There are multiple instances of output related to CS;

II. Standard: These projects utilise CS in some way as part of their methodology and have produced some form of output related to CS;

III. Partial: These projects reference CS but do not have them as a utilised component of the project. They tend to discuss future needs and potential of CS rather than using them directly.

Table 1: List of EU projects using CS, as found on the CORDIS website. Each project listing includes information on the type of project, the timeframe, the type of CS involvement, and output.

Name	Type of project	Timeframe	Type of CS involvement *(Additional details provided where pertinent)*	Output *(Where relevant citation also listed)*
Ecopotential Project	Blends Earth Observations from remote sensing and field measurements, data analysis and modelling of current and future ecosystem conditions and services in order to address long term, large-scale environmental and ecological challenges	1 Jun 2015 - 31 Oct 2019	Standard	2 peer-reviewed papers 1 book Citizen science for assessing ecosystem services: Status, challenges and opportunities (Schröter et al., 2017) Social license through citizen science: a tool for marine conservation (Kelly et al., 2019)

WET HORIZONS	Advances crucial knowledge and develops new tools and methods for rapid large-scale wetland restoration, including a mobile app for the visualisation of wetland status and a decision support system for policy makers	1 Sep 2022 – 31 Aug 2026	Standard CS used for data collection	*None listed: project ongoing*
Baltic Flows	Lays the foundation for developing new capacities and policies to effectively monitor and manage the quality and quantities of rainwater moving between locations	1 Oct 2013 - 30 Sep 2016	Partial Interested in technologies that would improve CS methods and advocates for future usage of CS; call for more attention, i.e., the creation of an EU framework future use	*None listed*
Measuring the Impacts of Citizen Science (MICS)	Creating a platform to help citizen science projects better understand the impact of their contribution	1 Jan 2019 - 31 Jul 2022	Integral Created an online platform featuring methods and guidelines for measuring the impact of citizen science, including 5 global case studies. Platform is freely available for other CS projects	>7 reports 2 white papers >2 methodologies and frameworks >7 peer-reviewed publications How to measure the impact of citizen science on environmental attitudes, behaviour and knowledge? A review of state-of-the-art approaches (Wehn et al., 2021)
'Extreme' citizen science engages remote communities (ECSanVis)	Enables communities with an emphasis on remote communities to participate in addressing issues concerning them, using smart tech that reflects specific needs and cultures	1 Jan 2019 - 31 Jul 2022	Integral Project is centred on CS in hard-to-reach communities and takes a bottom-up, local context-specific approach, involving citizens in the entire process from project design to use of results	25 early-career researchers supported 1 co-designed data collection app (Sapelli) 1 geographic information system (GeoKey) developed 20 global case studies 2 conference proceedings >6 book chapters >13 peer-reviewed articles 2 books Still in Need of Norms: The State of Data in Citizen Science (Bower et al., 2020)

				Citizen science impact pathways for a positive contribution to public participation in science (Skarlatidou and Haklay, 2021) Extreme citizen science: Lessons learned from initiatives around the globe (Chiaravalloti et al., 2021) Citizen Science Terminology Matters: Exploring Key Terms (Eitzel et al., 2017) Leveraging the power of place in citizen science for effective conservation decision making (Newman et al., 2017) Geographic Citizen Science Design: No-One Left Behind (Skarlatidou and Haklay, 2021)
Dancers	Develops new instruments and tools for environmental research in the Danube Region	1 Jan 2019 - 31 Jul 2022	Partial CS listed as a proposed research priority (i.e., for future usage) to promote cross-border environmental stewardship	*None listed*
AquaNES	Catalyses innovations in water and wastewater treatment processes and management through improved combinations of natural and engineered components	1 Jun 2016 - 31 May 2019	Standard	1 guidance document on the potential value of citizen science approaches Guidance on citizen science approaches (Brouwer et al., 2019)
HERCULES	Strives for the empowerment of public and private actors to protect, manage, and plan for sustainable landscapes of significant cultural, historical, and archaeological value at local, national, and pan-European scales	1 Dec 2013 - 30 Nov 2016	Standard	1 publication Contributions of citizen science to landscape democracy: potentials and challenges of current approaches (Shaw et al., 2017)
INTAROS	Develop an integrated Arctic Observation System (iAOS) by extending, improving, and	1 Dec 2016 – 28 Feb 2022	Standard	1 conference proceeding 1 peer-reviewed article

	unifying existing systems in the different regions of the Arctic			1 report Creating Synergies between Citizen Science and Indigenous and Local Knowledge (Tengö et al., 2021)
BiodivERsA	Conducts programming and funding research on biodiversity and nature-based solutions	1 Feb 2015 – 30 Apr 2022	Standard	1 toolkit 1 workshop BiodivERsA Citizen Science Toolkit For Biodiversity Scientists (Goudeseune et al., 2020)
BIG4	Amalgamate the cutting-edge methods of genomics, phylogenetics, informatics, taxonomy, semantic biodiversity publishing and citizen science, into highly competitive cross-disciplinary training programme	1 Jan 2015 – 31 Dec 2018	Standard	1 app 2 online training packages
Relate	Initiate a step-change in our understanding of how nature underpins human wellbeing	1 Oct 2017 – 31 May 2023	Standard	1 peer-reviewed article What motivates the masses: Understanding why people contribute to conservation citizen science projects (Maund et al., 2020)
EBONE	Harmonises biodiversity observation in Europe linking field observations with remote sensing	1 Apr 2008 – 31 Mar 2012	Partial Included in the Essential Biodiversity Variables	*None listed*
SCENT (Smart Toolbox for Engaging Citizens into a People-Centric Observation Web)	Alleviates barriers to engagement in environmental policies and raises awareness of publicly available information such as Copernicus initiatives	1 Sep 2016 – 31 Aug 2019	Integral	10 citizen science campaigns 1 curriculum 4 peer-reviewed articles >10 conference proceedings 1 toolbox
INTERACT	Seeks to build capacity for research and monitoring in the	1 Jan 2011 – 31 Dec 2015	Partial	*None listed*

	European Arctic and beyond		Included in outreach activities	
Ecofinders	Provide the European Commission with tools to design and implement soil strategies aimed at ensuring sustainable use of soils	1 Jan 2011 – 31 Dec 2014	Partial Mentions the care needed in future citizen science utilisation	*None listed*
ECLAIRE (Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems)	Investigates the ways in which climate change alters the threat of air pollution on European land ecosystems including soils	1 Oct 2011 – 30 Sep 2015	Partial Mentions citizen science as a potential tool in instigating behavioural change	*None listed*

3.3 Guidelines for Citizen Science in wetland research

On the basis of the research conducted in the present report, a guideline for use of citizen science for wetland research has been created. This guideline contributes to the evolving discourse on the use of citizen science methods in wetland research and restoration. It is designed to be used as a guide, recognising the need for context-specific decision-making and considerations. Participatory projects that involve the public contain a number of stages, from initial engagement activities to feedback and ongoing facilitation (Starkey et al., 2017). Furthermore, it should be noted that CS projects are not always easy to categorise. For instance, large-scale data collection projects may influence policy on local or regional scales as well as on national scales, and similarly some community-based projects may generate large-scale implications (Shirk and Bonney, 2015). This guideline, therefore, operates as a guide whereby the categories, methods, and steps outlines offer useful insights that can be deliberated upon and adapted to the CS project in question.

3.3.1 Incorporation of existing frameworks and guidelines

Throughout the guideline, there are schemas and elements incorporated from other researchers active in the field of CS. An overview of the those utilised in the creation of this guideline can be found in Table 2. The work of these authors is incorporated throughout the steps, with particular diagrams or images included as deemed beneficial.

Table 2: List of CS frameworks that have informed the CS-Wetlands guideline in the present report. The frameworks are listed in chronological order.

Author(s)	Year	Title of publication	Purpose/Aim of framework	Field of interest
Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., & Shirk, J.	2009	Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy	Inform the fields of biodiversity monitoring, biological research, and science education and provide an insight into the culture of citizen science	Ornithology
Tweddle, J.C., Robinson, L.D., Pocock, M.J.O. & Roy, H.E	2012	Guide to citizen science: developing, implementing, and evaluating citizen science to study biodiversity and the environment in the UK	Support people already involved in citizen science, and those new to it, within the UK	Biodiversity and the environment in the UK
Wiggins, A., Bonney, R., Graham, E., Henderson, S., Kelling, S., LeBuhn, G., Littauer, R., Lotts, K., Michener, W., Newman, G., Russell, E., Stevenson, R., & Weltzin, J.	2013	Data Management Guide for Public Participation in Scientific Research	Provides a step-by-step introduction to the data management life cycle	Data management
Pocock, M.J.O., Chapman, D.S., Sheppard, L.J., Roy, H.E.	2014	A Strategic Framework to Support the Implementation of Citizen Science in Environmental Monitoring	Provide a decision framework to guide whether and when to use a citizen science approach for environmental monitoring	Environmental monitoring in freshwater and terrestrial environments
Bonney, R., & Shirk, J.	2015	Informing a Framework for Citizen Science within the US Fish and Wildlife Service (USFWS)	Inform and advise the USFWS	Immediate research and education needs of the USFWS
Starkey, E., Parkin, G., Birkinshaw, S., Large, A., Quinn, P., & Gibson, C.	2017	Demonstrating the value of community-based (‘citizen science’) observations for catchment modelling and characterisation	Investigate the value of community-based (‘citizen science’) observations form modelling and understanding catchment response as a contribution to catchment science	Hydrological modelling
De Vries, M., Land-Zandstra, A., & Smeets, I.	2019	Citizen Scientists’ Preferences for Communication of Scientific Output: A Literature Review	Investigate participants’ preferences for the communication of data, findings, and scientific publications	Multidisciplinary
Brouwer, S., van Aalderen, N., van Dorssen, Al., & Smith, H.	2019	Guidance on citizen science approaches (Deliverable 5.4)	Encourage and support professionals at such sites in undertaking a citizen science initiative	Water treatment systems
Salmon, R.A., Rammell, S., Emeny, M.T., & Hartley, S.	2021	Citizen, Scientists, and Enablers: A Tripartite Model for Citizen Science Projects	Contributes to strengthening the collaborative delivery of both valuable scientific research and public engagement	Citizen science, conservation biology
Newby, C.	2022	For Peat’s Sake! Climate change, Citizen Science,	Identify a sustainable framework for community-based peatland	Peatlands, community

		and the Northwest Territories	environmental monitoring that engages Indigenous communities, embraces Traditional knowledge, and increases scientific literacy	science, Indigenous knowledge
Hecker, S., & Taddicken, M.	2022	Deconstructing citizen science: a framework on communication and interaction using the concept of roles	Provide a structured way to capture communication and interaction in and about CS for further scientific reflection and practical application	Science communication

4 The Guideline

The framework is divided into five stages: planning; project design; development; live; and data analysis and reporting (Fig. 5.1), with an additional category for tasks that occur throughout the project. Within each of these stages there a number of steps, which are outlined below.

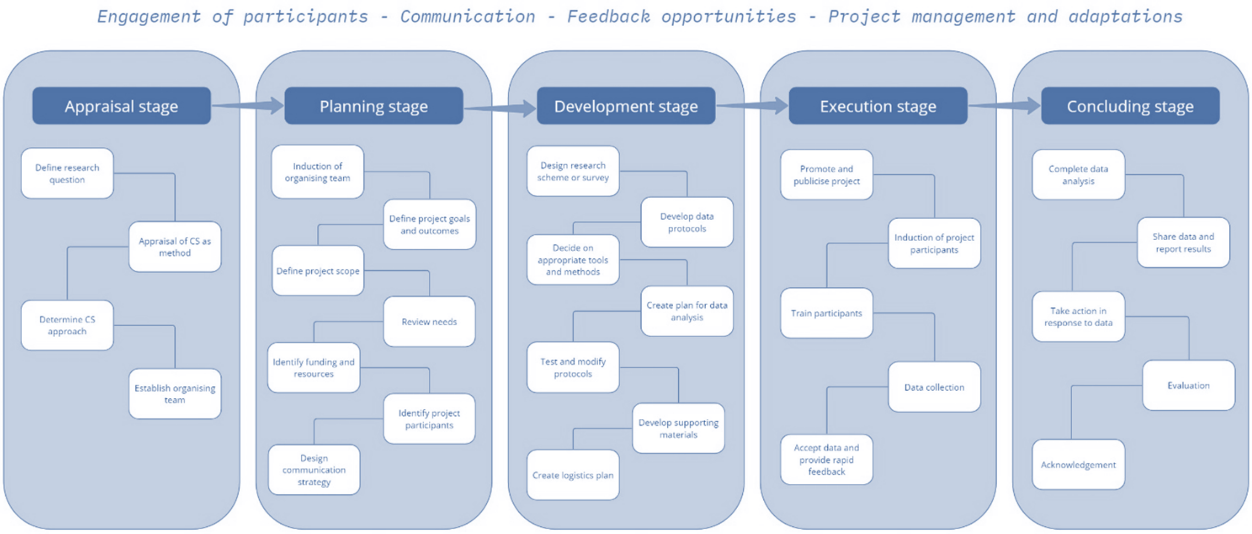

Figure 3: Diagram displaying the citizen science and wetlands framework proposed by the present guideline.

4.1 Ongoing tasks

4.1.1 Engagement of participants

Participant engagement is what sets CS apart from conventional science (Shirk and Bonney, 2015), thus is, as expected, integral to CS projects. Projects will differ in terms of level of participant engagement, with some having citizen scientists involved only in the data collection aspect, and others with citizens engaged through project design and management stages as well. It is included here as an ongoing task because along the way, the implications and opportunities of participant engagement should be considered (Shirk and Bonney, 2015). This means that, depending on the project design, alterations can be made throughout, in response to feedback and periodic evaluation. Having said that,

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there are particular moments in the process where is more relevant to be considering participant engagement; these are (e.g., *4.5.2* *Induction of project participants* and *4.6.5* *Acknowledgement*)

4.1.2 Communication

Communication is a crucial element of CS, which is in no small part down to the amount of people involved, their varied roles, and the need for interaction between both people and roles. Indeed, Hecker and Taddicken (2022) contend that new modes of communication and interaction emerge in CS at both the micro and meso level, which is due to the change in relationship and roles of actors. They use the micro level to denote interactions between individuals and their roles on a small scale, i.e., within a given CS project, where members of the public may take up project initiator roles or scientists may be involved in recruitment (Hecker and Taddicken, 2022). The meso level is understood to be groups of actors and their communication and alterations in role on a structural level, which entails notions of traditional roles being challenged with the public taking on an active role in knowledge production processes rather than the former passive role, and scientists perhaps becoming more engaged in facilitation roles than knowledge producers (Hecker and Taddicken, 2022). Thus, communication in CS is a key element (Pocock et al., 2014) which takes on different forms throughout and within the project. In this way, it may be understood as both a process and as a tool (Hecker and Taddicken, 2022).

The following section is split into three parts: communication between members of the organising team, communication with participants, and communication with the general public. All of these are present throughout the process, whereas other forms of communication, i.e., communicating results with policymakers appear at specific moments, so are included further on in the framework.

Communication between members of the organising team

Communication between members of the organising team is naturally key to the success of the project; it is crucial that these members are on the same page and have open communication channels. This communication and the ability to successfully execute the project will both be facilitated by and require trust between the members, without which it can be difficult to tackle problems and issues (Hidalgo et al., 2021). One possibility is to use external facilitators – either throughout or in the initial stages – who can create the necessary condition for open communication; they may also be able to support collective decision-making processes (Hidalgo et al., 2021). Depending on how the project is formulated, who is involved, and what sensitivities or other intricacies might be at play, this may be good practice. It may not be necessary with the key step here being that options on how best to communicate are considered (including, e.g., which platform to use, how often, etc.) and viewpoints are not left implicit.

Communication with participants

A project will offer multiple moments of communication with participants, including during recruitment, the sharing of results, and evaluation; these are included in the corresponding step of the framework. In this section, the focus is more on the purpose and value of communication. Participants will be keen to know how their contributions are making an impact and may withdraw from a project if they perceive a lack of value in their contribution (de Vries et al., 2017). Therefore, communicating the usefulness and value of participants' contribution to them is key. Scheduling in communication moments and designing materials is thus important to communicating the why and how of a project. Furthermore, the project should be willing to change tack if the communication strategy is not working or participants express the need for other formats, mediums, or types of communication. Emphasising the importance of communication, Hecker and Taddicken list the communication and interactions processes as inseparable from the scientific activities in CS (2022). The authors cite Druschke and Seltzer (2012) who, on the back of learnings from a project they reported on, emphasised the need for considering participants' viewpoints and needs as well maintaining active communication and exchange between scientists and participants.

Opportunistic projects will need to focus on communication with participants less, in the sense that it is not ongoing communication that is required. They will, however, have to ensure that communication materials are very clear, precise, and engaging as there will not be options for in-person training or asking questions or making clarifications. This a specific skill, requiring input from communication experts and trialling of materials.

Communication with the general public

Alongside communication with participants of the project, it is useful to communicate the project activities and findings with the general public. This can operate as a form of ongoing recruitment, as well as a way of expanding the pool of people learning about the topic and scientific processes without necessarily acting as a participant. Communication can be done through mass media formats; however, this can be risky as it is not certain that a project will be picked up by journalists (Pocock et al., 2014). Alternatively, more directed routes of communication are also possible, including local media campaigns and social media (Pocock et al., 2014). Utilising a varied strategy of communication with different outlets and mediums may be the best format for reaching a wide audience demographic (Pocock et al. 2014).

4.1.3 Feedback opportunities

As highlighted by Starkey et al. (2017), many authors have discussed ongoing feedback as being essential in CS projects. This includes Tweddle et al.'s Guide to Citizen Science (2012) and Shirk and Bonney's Citizen Science Framework Review (2015). Due to the accepted importance, this step is included in the ongoing steps, drawing attention the fact that it can, and should, be done throughout the process of conducting a CS project. There are multiple moments to gain feedback from the participants on how they are finding their involvement and to give feedback on their participation and progress. One key type of feedback regards what the research is showing and ways that the data and research are being used (Shirk and Bonney, 2015); others involve feedback on how the measurements are being taken or how the project is being received by the public and/or policymakers.

4.1.4 Project management and adaptations

Project design and evaluation should be understood as going hand-in-hand, which also means that project design should be considered an ongoing and iterative process (Shirk and Bonney, 2015). In practice, this implies that attention should be given to whether the project is still meeting the assigned goals and objectives as it moves forward. If not, then decisions can be jointly made on what the best next steps are to get the project back on track.

4.2 Planning stage

4.2.1 Defining the research question

The first step, as is the case for other scientific methods and processes, is to determine and define the research question, which could be driven by scientific, community, or policy needs (Tweddle et al., 2012). The specifics of defining a research question will be not expanded upon here, except to mention that CS lends itself particularly to research questions that have a large spatial and temporal scope (Bonney et al., 2009) and to highlight the importance of the research question with an example.

Some CS projects are instigated and implemented by non-scientific actors, and may be primarily focused on the public outreach aspect of CS. An example of this is given by Salmon et al. (2021) as they discuss the Great Kererū Count in Aotearoa New Zealand, which was initially led by two NGOs aiming to engage and educate the public and conserve the habitat of these birds. Scientists were later brought on board. Despite attaining a large data set (5000 participants providing records of occurrence of the kererū across the country) that would have been unattainable on usual research budgets, some disadvantages arose due to not involving scientists from the outset (Salmon et al., 2021). The authors conclude that if scientists had been involved from that stage, more scientifically valuable data could have been attained, citizens would have contributed to furthering scientific knowledge in a sharpened manner, and the NGOs would have also realised their desired levels of engagement (Salmon et al., 2021). This example underlines the significance of scientific engagement and of a well-formulated research question and accompanying research design, for the scientific robustness as well as for participant engagement, especially given contributing scientifically valuable data being a strong motivator (Greenwood, 2007; de Vries et al., 2019), i.e., in this example, over 90% of participants identified this as a motivating factor of engagement.

Other projects may begin from the starting point of wanting to pursue CS before searching for an appropriate research question. In Bonney et al. (2009), the model lists *choose a scientific question* as the first step, with the assumption of a predetermined CS approach. This is perhaps most likely when organisations are initiating the project and view CS as a useful engagement or outreach tool, as mentioned above (i.e., Salmon et al., 2021). Although this may present challenges, it may also be that the organisation or research centre have CS as part of the overall methodology, i.e., CLO designs public participation projects that fit within the organisation's science or conservation mission, whilst having a strong emphasis on how citizen scientists can be involved (Bonney et al., 2009), or the Scottish Environmental Protection Agency (SEPA) who conducted a report on how CS may be used to assess environmental pressures relevant to their organisation, including using case studies designed to help develop SEPA's approach to implementing CS (Pocock et al., 2014). Care should be given to ensuring that the project design delivers both scientific and educational outcomes. In this case, if the desire for a CS approach is the starting point, particular attention should be given to ensuring scientific outcomes are feasible, i.e., the CLO has CS experts who are part of the project design and so can ensure this is the case even when CS is one of the major starting aims. If the focus is on engagement, Pocock et al. recommend asking: *"can you extend your engagement activity into meaningful and relevant citizen science?"* (2021, p.16).

Box 4.1 Implementation for wetlands

There remain many knowledge gaps in wetland research, management, and policymaking; Ramsar (2018) describe many of these knowledge needs as not requiring cost-intensive and sophisticated monitoring. Alongside other options, they list CS as one of the most cost-effective and feasible solution for tackling information gaps (Ramsar, 2018). Thorslund et al. (2017) conducted an assessment of the extent that research has addressed large-scale dynamics of landscape systems with multiple wetlands (what they term "wetlandscapes"). The authors find that there is a clear gap between traditional research expertise from local wetland projects and the translation to larger scales, which has an impact on various solutions (i.e., management, engineering, policy) for global wetland deterioration (Thorslund et al., 2017). This is consistent with Murry (2019), who highlights the emergent nature of land-landscape scale conservation. Ramsar (2018) have stated the need to improve current wetland inventories and to improve communicating the research to the public. These examples give a brief insight into the knowledge gaps and open questions for wetland research; one of the major aspirations is also large-scale insights. One way to obtain the vast amount of data required to study large-scale patterns in nature is through CS, where data can be collected across an array of locations and habitats over time spans of years or decades (Bonney et al., 2009). Thus, there are both clear research opportunities that can be identified and a potential for CS to contribute towards answering the formulated research questions.

4.2.2 Appraisal of CS as method of choice

One of the first questions to be asked before initiating or embarking on a CS project is whether this is the right approach. Although there is a myriad of benefits brought on by using CS, as a method it is not able to provide solutions to every problem (Shirk and Bonney, 2015). CS requires significant time and resource investment from multiple partners who may have distinct needs and objectives (Shirk and Bonney, 2015), and therefore, projects may become complicated rather quickly with this approach. This is to say that careful consideration of whether CS is an apt choice for a particular question is required at the start of a potential project. Tweddle et al. recommend asking, *"Is it [CS] critical, desirable, or will it detract from the overall aims of the project?"* (2012, p.2). They also provide a number of key considerations that contribute to reaching a decision (Fig. 4). Pocock et al. (2014) developed a guideline for considering whether or not CS is the right approach, which includes considering and ranking according to the clarity of question, importance of engagement, resources available, scale of sampling, complexity of protocol, and motivation of participants. These various factors are listed in more detail in their report. The framework presented in the report can be best understood as guidelines rather than rules, with creative solutions possible and not all criteria needing to be met (Shirk & Bonney, 2015). At such an early stage in the process, it is possible that not all of the points included in Fig. 5 will have been comprehensively considered, so it may be beneficial to return again to these questions at a later stage or to anticipate possible responses to the questions.

Key considerations

- What geographic or temporal scale are you aiming to cover?
- How much data do you want to gather and analyse?
- Can volunteers help to gather and analyse these data?
- Are there other ways of gathering or analysing the data?
- To whom will your project appeal?
- What might be their motivation for taking part?
- Can you support participants' involvement by providing training and co-ordination?
- Do you have the resources to develop and publicise the project and share findings with participants?
- Are similar projects already in existence? It may be more efficient to add to existing schemes or work with other organisations than to set up a new project.

Figure 4: List of questions to consider when choosing whether or not to pursue CS (Tweddle et al., 2012)

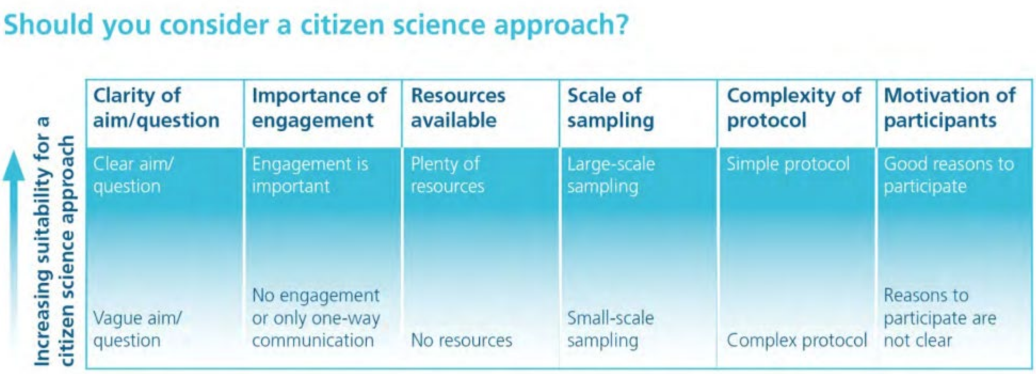

Figure 5: Six categories to consider that aid in the appraisal of whether CS is the appropriate choice in a given situation (Pocock et al., 2014)

There are also many different ways to incorporate and implement CS. Shirk and Bonney (2015) point out there are various types of projects, so the question of whether or not to implement CS may not be a yes or no question. Rather it may be a question of how it may be best implemented. In addition to their schema for determining the suitability of a CS approach, Pocock et al., (2014) have created a decision framework. The objective of this framework is to provide guidance both about whether it is suitable and in what form (Pocock et al., 2014). The framework may be used for projects with an existing clear aim or may be used to refine and clarify an aim as it presents questions that may not have previously been encountered. Another approach is to examine whether CS will be able fulfil outcomes on the individual, scientific, and system levels (Brouwer et al., 2019). If only one of these is fulfilled or only vague outcomes are able to be ascertained, it might be that CS is not the most appropriate approach, or that more time needs to be spent understanding what these outcomes may be. Brouwer et al. (2019) use the example that if only scientific outcomes can be determined whilst individual or system outcomes are neglected, it implies that CS is primarily being used as a form of cheap data collection.

Although much of the critique of CS can be managed through intentional research design and inclusion of a broad range of skillsets in the organising team, there are some disadvantages of CS. These should be carefully considered when assessing whether or not CS is an appropriate tool. Pocock et al. (2014) provide a useful list of some disadvantages which can be deliberated upon as well as some checks that should be made before embarking on a CS project. The latter of these are listed by Pocock et al. (2014) as precursors to their decision framework, whereas here they are included as part of the planning stage. Ultimately the following should be considered when deciding whether CS is an appropriate tool (from Pocock et al., 2014)

- **I.** Do you have the resources to carry out and successfully complete the project? This includes the ability to provide feedback to volunteers throughout the process, which can be costly but is a necessary investment for structured projects, and the expenses of infrastructure for data acquisition (e.g., online databases or smartphone apps), which can also be relatively high.
- **II.** Is there a commitment to working with participants as a research method? Are you willing or able to invest the time and resources in the induction of project participants? This is important to alleviate tensions between the motivations of participants and the needs of organisers.
- **III.** Do you have the expertise to conduct the data analysis? This may require complex analytical approaches, in turn requiring expertise and resources.
- **IV.** Is there a long-term commitment within the organising team to keep the project and surrounding infrastructure running? Is there a long-term commitment from the participants or alternative arrangements in place, e.g., ongoing recruitment strategies or opportunistic designs?
- **V.** Is there a varied skillset present in the organising team, e.g., expertise in targeting particular participants.
- **VI.** Are the aims and questions of the project clear for all parties? Is the protocol for data collection both not overly complex and appropriate for answering the research questions?

Box 4.2 Implementation for wetlands

As mentioned in the previous step, CS is particularly helpful for answering questions that have a large spatial or temporal scope, i.e., monitoring studies to detect pattens of species occurrence over time or space (Bonney et al., 2009). If the research question demands such an extensive dataset, CS would certainly be worth investigating further. One key research gap identified by Ramsar (2018) is the knowledge of wetland extent; as global ecosystems with local and regional particularities and with varying degrees of research conducted, improving current inventories is a key step.

Expansion of CS will help fill these knowledge gaps, allowing to inform wetland management, investment, and conservation (Ramsar, 2018). Conservation on the large-landscape scale is considered still an emerging paradigm, with this form of conservation applied to wetland resilience with an interdisciplinary perspective being long overdue and immensely important (Murry, 2019). Having said that, the need for interdisciplinary approaches in broader wetland research has been acknowledged for decades (see Wilcox, 1987). Wetland research tends to require involvement from different disciplines and stakeholders, including (eco/geo)hydrologists, archaeologists, (plant/animal) ecologists, local/rural residents and communities, soil/sediment chemists, place-based knowledge holders, remote sensing experts, and more (Wilcox, 1987; Flood, 2022). This identified need and approach strengthens the case for CS approaches for wetlands, as they also require this approach. That conservation of wetlands requires a landscape scale approach (Murry, 2019) also contributes towards the value of taking a CS approach, with data collection possible at greater spatial scales as well as the fact that CS may also be able to act as a learning tool, civic empowerment instigator, and policy instrument (Shirk and Bonney, 2015; Brouwer et al., 2019).

However, despite the merits of CS for many wetland research and conservation questions, careful consideration should be given to whether the research question permits a CS approach. Certain questions require tools, equipment, and expertise that may be beyond the scope of a CS project. Particular fields, such as soil science and ecosystem ecology, have not utilised CS to the extent that others have (Reed et al., 2018). This is largely due to perceived difficulties with research in these areas often requiring substantial labour and technical experience (Reed et al., 2018). Both soil science and ecosystem ecology are relevant to wetlands, but perhaps the most apparent obstacle with CS and certain wetland research questions is that of GHG flues in wetlands. There is a large reduction in the number of studies using CS and GHG, as compared with biodiversity, with GHG research often requiring specialised and costly equipment and higher degrees of knowledge on the interpretation side.

That being said, Reed et al. (2018) conducted a proof-of-concept using CS to measure GHG fluxes in meadow ecosystems, in which they demonstrate that it is feasible for collecting scientifically relevant data as well as encouraging local conservation. There is an element of risk involved with wetland research, both on the part of the wetland itself and the researcher.

Wetlands can be tricky environments to conduct research in, especially where participants may need to venture away from boardwalks or pathways, as they may lose their footing and be immersed in the water, the conditions could be foggy or otherwise provide difficulties in visibility, and they may get lost in the environment.

This highlights the need for a thorough risk assessment (as included in 4.4.7 *Create logistics plan*) and adequate informational guides and advice (4.4.6 *Develop supporting materials*). In terms of the risk to the wetland itself, research and field monitoring can disturb the integrity of the wetland (Bryzek et al., 2022). Bryzek et al. (2022) argue that the activities of wetland managers and researchers should be held to higher standard than that of the public because the scientific community has an obligation to reduce any harmful impacts they may have to the areas they conserve and study. In this case, the public – or members of the public – are conducting the study, so it can be rationalised that they should be held to these same standards in this instance. Therefore, a vital consideration when determining whether CS is an appropriate tool in a given instance is whether or not the heightened presence of the participants in the area will be harmful to the peatland to an unacceptable level, and what the possible ways of mitigating this are.

4.2.3 Determining the CS approach

There are, broadly speaking, several different approaches that CS projects can follow. Salmon et al. (2021) provide a useful, elementary characterisation of 'top-down' projects wherein scientists engage with citizens to collect data and 'bottom-up' projects whereby citizens initiate the research process and data gathering in order to answer some question. Thus, the configuration of the project may be shaped by the initiator, although it may also alter throughout the project. The starting point can be understood as particularly important as whether a scientist, community or organisation initiates the project sets the tone for how various people will engage in the project and what degree of participation people will have. Salmon et al. (2021) use the example of the Great Kererū count in Aotearoa New Zealand which was initiated by two NGOs with public engagement, education, and conservation as the key goals, and an implicit intent of contributing data for scientific purposes. The lack of involvement of scientists from the initiation stage and through the first two years of the project was considered to compromise the scientific utility of the collected data (Salmon et al., 2021). Engagement alone is not generally considered to be CS (Greenwood, 2007; Miller-Rushing et al., 2012; Pocock et al., 2014); in this particular instance, Salmon et al. (2021) did categorise the project as CS on the basis that those involved did so. However, it is not ordinarily the case, with a strong emphasis being placed on producing data that is scientifically valuable.

A useful way for deciding what kind of CS approach to take is that set forth by Bonney et al. (2009) who categorise projects as contributory, collaborative or co-created. A diagram form of this scheme can be seen in Fig. 6, whilst an adapted version of their schema is provided by Miller-Rushing et al. (2012), with definitions listed. Contributory projects refer to projects designed entirely by scientists with participants involved primarily in the data collection (Tweddle et al., 2012). These projects tend to be large-scale, top-down projects aimed at addressing questions requiring extensive (spatially or temporally) data collection (Shirk and Bonney, 2015). An example, given by Shirk and Bonney (2015), for this format is eBird, an online database of bird observations offering real-time data about bird distribution and abundance which is managed by CLO. The extensive data collected can be used by scientists or to aid conservation efforts (Shirk and Bonney, 2015). The approach has been the most commonly applied approach (Brouwer et al., 2019), although Miller-Rushing et al (2012) also point out that much of the research conducted in the past by amateur scientists followed a co-created model, where projects may even have been completely independent of professional scientists. Collaborative projects are also largely designed by scientists, but participants are involved in more than one stage of the scientific process, which could mean contributing or analysing data or communicating findings (Tweddle et al., 2012). This largely involves the join analysis of data or dissemination of results (Schröter et al., 2017). Co-created projects are usually developed by members of the public who reach out to scientists and researchers for assistance with their projects which tend to be local or regional in focus, or focusing on policy issues (Bonney and Shirk, 2015) or designed collaboratively between scientists and communities (Tweddle et al., 2012). Within this category, participants are frequently involved in data interpretation and dissemination alongside collection (Bonney and Shirk, 2015) and, indeed, they may be involved in most or all steps of the scientific process (Tweddle et al., 2012; Miller-Rushing et al., 2012). Additionally, there are contractual projects whereby the public contract research from scientists (Salmon et al. 2012), and collegial contributions whereby the public conduct research independently (Salmon et al. 2012) or within minimal or secondary involvement of professional scientists, i.e., consulted for advice or specific analyses (Schröter et al., 2017); these may or may not be recognised by institutionalised science entities (Salmon et al., 2012).

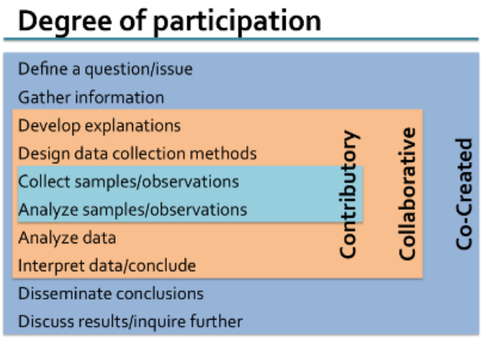

Figure 6: Visualisation of the degree of participation of members of the public in three CS project categorisations: contributory, collaborative, and co-created (Shirk and Bonney, 2015)

These categories are useful for clarifying the project and the participant involvement, as often terms such as public participation, volunteer-based monitoring, and citizen science mean different things to different people (Miller-Rushing et al., 2012). Salmon et al. (2021) describe these delineations as a continuum, relaying that they should less be understood as distinct categories, but rather as a spectrum, with overlapping and intermediary options possible (Brouwer et al., 2019). Haklay (2013) describes the relation between the different options as levels (Fig. 7), with the objective to be to try and move to the highest level that is suitable for a specific project. These levels move from crowdsourcing at the bottom where citizens are involved mostly as sensors through to *extreme citizen science,* where participants are involved in many of the steps. He describes the framework as a typology that focuses on the level of participation of the citizen scientists (Haklay, 2013). This level is part of what makes up the relationship between the citizens and scientists, which Salmon et al. (2021) describe as the underlying feature of what these options demonstrate: the importance of this relationship in determining the shape of the project. Although these options may be discussed as a spectrum or series of levels, ultimately what is most significant is assessing which option best meets the needs of the project and participants. Shaw et al. (2017) describe Haklay's model as a seminal one that expresses the underlying power dimensions at play. They emphasise that the involvement of the public is usually done in a way that actually excludes them from having any real effect on the outcomes, whilst satisfying requirements of funders or planners (Shaw et al., 2017). In any model, these concerns should be incorporated to ensure genuine and tangible input from participants, and that as much as possible participant are involved throughout the process.

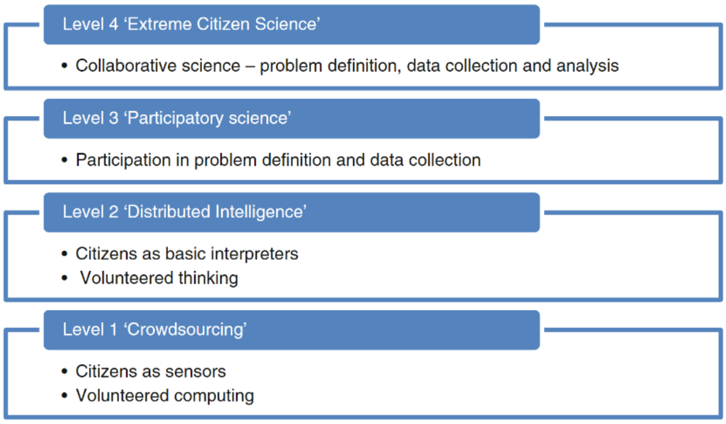

Figure 7: Another method of thinking about different levels of participation in CS (Haklay, 2013).

Brouwer et al. (2019) have created an overview of advantages for different types of CS. It should be noted, however, that the typology acts primarily as a means and springboard for further discussion on what shape a particular CS project will take. An important finding from Phillips et al. (2014) was that similar participant learning outcomes were achieved across different projects with different CS approaches (i.e., contributory, co-created, etc.).

4.3 Implementation for wetlands

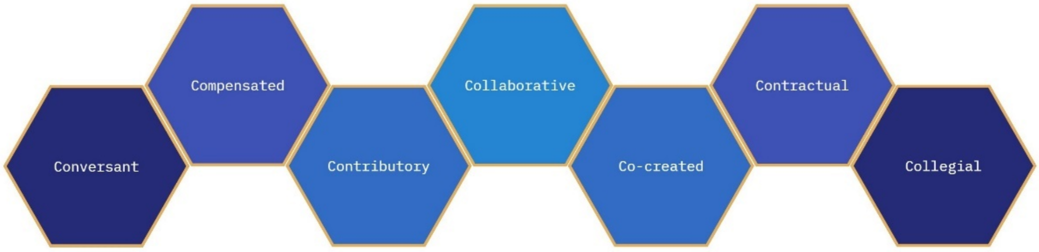

Figure 8: A new way of thinking and visualising the categories of CS proposed by this report

This report conceptualises a structure of seven varying forms of CS (Fig. 8). This builds on the work of previous authors, particularly that of Bonney (2009), Miller-Rushing et al. (2012), and Shirk and Bonney (2015). In contrary to Haklay's (2013) scheme and the contention that the aim should be to move as high up the levels as possible, the scheme presented by this framework is more aligned with a continuum. This draws from Salmon et al. (2021) who describe the delineations as a continuum with overlapping and intermediary options. Haklay's understanding that citizens should be as involved as is suitable for a particular project remains, with that being something established by the initiators of the project.

Participant involvement and the need to heighten this where possible is considered important as it can be used to strengthen strategic knowledge on the environment, scientific literacy, and the empowerment of citizens (Schröter et al., 2017). The framework additionally views movement between the options and in between options as sensible, depending on the project. This guideline also acknowledges Haklay's (2013) description of the participation of the citizen scientists being the focus, and therefore adds several categories to the typology. A definition of these categories can be found in Fig. 5.8. Contributory, collaborative, and co-created projects are in common use in the literature on CS, whilst contractual and collegial are mentioned intermittently but tend not to be included in typologies. The categorises of compensated and conversant have been introduced by this framework as a result of mention in the literature of the possibility and relevance in some projects of paying participants and based on discussions of citizen scientists including experts.

4.2.4 Establishing the organising team

Successful citizen projects require a multidisciplinary team (Bonney et al., 2009) with many stakeholders playing a role in projects, including educators, communicators, community managers, societal organisations, policy makers, (local) government (Hecker and Taddicken, 2022), landowners, local and national businesses, interested researchers and naturalists, and society or club members (Tweddle et al., 2012). As they are integral to the project (Newby, 2022), all of the relevant stakeholder groups should be engaged with during the project development, some of which may join the organising team. Here is the organising team refers to those who are actively involved in the design, development, execution, and analysis and reporting stages. This can and should include citizens, but there will be citizens involved in carrying out the CS who are not in the organising team.

In the organising team, Bonney et al. (2009) outline the need for the following:

I. A researcher to ensure the project's scientific integrity, develop protocols to collect quality data, and analyse and publish results;
II. An educator to explain the project's importance to participants, pilot, and rest protocols with potential participants, develop clear support materials, and ensure appropriate participant feedback;
III. An information scientist to develop the database infrastructure and technology required to receive, archive, analyse, visualise, and disseminate project data and results, and;
IV. An evaluator to ensure that the project contains measurable objectives from the start and gathers data that assesses the project success according to these objectives.

This is just an insight into how it is conceptualised by Bonney et al. (2009), with other roles required depending on the project. For smaller projects, in particular community-led projects, it may be that teams do not cover all these skillsets. They may be able to partner with other organisations to fill any gaps, which could be found through the projects and resources available on SciStarter, CitizenScience.org or EU citizen-science.

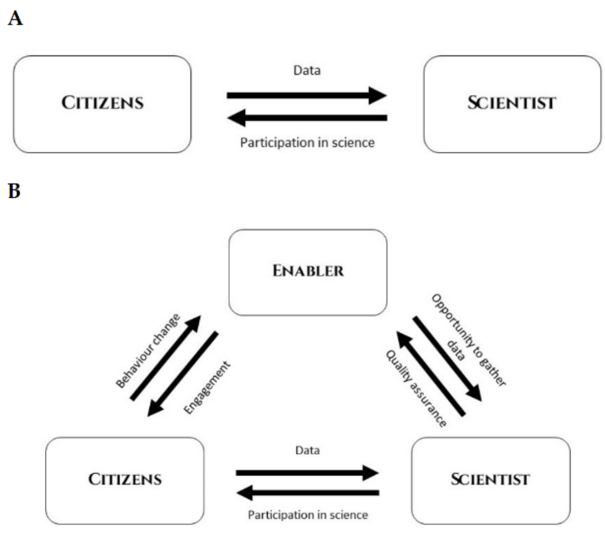

Figure 9: Diagram displaying the contrasting representations of CS with A demonstrating the traditional two=party model and B showing an idealised tripartite model (Salmon et al., 2021).

Salmon et al. (2022) emphasise the need for a facilitative role which they term the enabler (or alternatively the advocate or educator). This role may overlap with some of those elucidated by Bonney et al. (2009), particularly the evaluator and educator roles. There is, however, a more explicit focus on ensuring the collaboration goes smoothly; this calls for greater expertise in facilitation, communication, and public engagement (Salmon et al., 2022). The authors represent their understanding in a tripartite model, which can be seen in the bottom portion of Fig. 9, (A) with the above model demonstrating their understanding of a traditional two-party model (B). As mentioned, this model has overlaps with other understandings of the team members and skills needed in a CS project, with the literature showing a general trend towards seeing CS projects as more encompassing that only involving citizens and scientists. This is an active area of inquiry, with there being little research in the interaction and communication processes between various actors (Hecker and Taddicken, 2022).

4.3 Project design stage

4.3.1 Induction of the organising team

This stage entails the organising team making foundational decisions on how to work together (Newby, 2022) and familiarising themselves with one another, including gaining a deeper understanding of one another's motivations, expectations, needs, and any additional skills required but not yet covered. Following this, this stage also includes defining the roles and responsibilities of each member of the organising team. Each of these aspects are discussed in the following section. This stage involves the induction of the organising team specifically, with the same evaluations made with the project participants in *4.5.2 Induction of project participants*. This may seem an elaborate section, focusing heavily on people management before undertaking the research, however, the successful conservation, adaptation, and management of wetlands requires managers to strike a balance between potentially competing objectives (Murry, 2019). In this way, learning and enhancing skills relating to facilitation, diplomacy, people management and more, as they pertain to wetlands, is a highly beneficial process, for future management of wetlands.

Hidalgo et al. (2021) emphasise the need to address real-world problems through CS, regardless of the potential academic impact, whilst multiple authors (Greenwood, 2007; Salmon et al., 2021) emphasise the need for the data and results to contribute to scientific processes and research. As such, CS projects tend to sit at the nexus of these two and attract people with varied motivations and expectations. Discussing and determining these within the organising team, particularly the non-scientists is an early input into the project process (Newby, 2022). These may vary between wishing to improve the community ecology, changing policy, increasing social interaction, gaining new understandings, publishing results in peer-reviewed journals, and more. As multiple different, potentially competing, notions are at play, there is likely some variance, and even tension, present. Rather than avoiding the complexities, it is useful to create a space where people can contribute and share their perspectives (Hidalgo et al., 2021). Brouwer at al. (2019) point out that desired individual outcomes often remain implicit in CS projects and recommend that these are made explicit before the project starts. This will increase the likelihood that they are realised (Brouwer et al., 2019). Here it is beneficial to use facilitation strategies that are used outside of the realm of academic discourse and conceptual theories and are instead aimed at creating a shared language (Hidalgo et al., 2021). Hidalgo et al. (2021) recommend using reflexivity, use of visual language and systems thinking as a starting point, with participatory design techniques such as diagrams, icons, and storytelling.

In terms of needs and gaps within the organising team, it is useful to evaluate firstly where it is already residing, which involves identifying the contributions of the different actors in the project development team (Shirk and Bonney, 2015). In this way, it can be assessed where known strengths lie and where additional strengths are needed. It also acts a means to assess where pathways to more learning may be within the organising team, equipping the team members with the opportunity to upskill and the confidence to do so. After this, any needs that are lacking within the team will need to be addressed, which can be done by recruiting additional organising team members, through partnerships, or contracting particular aspects of work.

Another early input into the process is describing the roles and responsibilities and outlining the project governance and power structures involved (Newby, 2022). Discussing the interpretations and expectations of each role, reaching a common and explicit understanding, will avoid any confusion or conflict later in the project. Where science and society are traditionally seen as separate entities, the boundaries between these actors being to blur in CS as members of the public are not external audiences but part of the project itself (Hecker and Taddicken, 2022). Yet, there are undoubtedly still distinctions in how the different actors see one another and in the weight of perspectives; often participants will respect and appreciate the knowledge of the professional scientists, whilst at the same time building their own knowledge and, over time, be better placed to suggest questions and move up the ladder of participation (Haklay, 2013). This makes for a complex and changing dynamic and is one of the reasons why openly and continuously discussing the project roles and responsibilities is so key. In CS projects, the different actors come from different communities with differing logics and aims, which impacts the understandings and perceptions present (Hecker and Taddicken, 2022). These have broad-ranging effects on, e.g., expectations, language usage, motivations, value systems and aims for research and participation (Hecker and Taddicken, 2022). Thus, is it important to give the process of defining roles and responsibilities (and the associated expectations etc.) ample time. For long-term projects, this is particularly important (Pocock et al., 2014). This will include determining how communication and interaction will occur. This internal communication is important for all roles and across all active members of the CS project.

A useful tool for visualising convergence and divergence – which may cover motivations, expectations, needs and roles - within the project development team is a concept map, wherein goals and assumptions can be made explicit, and it is possible to see where these are shared and where they are different (Shirk and Bonney, 2015).

Box 4.4 Implementation for wetlands

Wetlands contribute to a broad range of different ecosystem services, with the four classifications of ecosystem services (i.e., cultural, provisioning, regulating, and supporting) being met in some way by wetlands. These ecosystems are often associated with long standing cultural practices which have allowed human societies to thrive and adapt to environmental change (*Culture & Wetlands | Convention on Wetlands*, n.d.) as well as develop a variety of cultural values, belief systems and associated practices (Papayannis and Pritchard, 2016). Many wetlands the world over have spiritual and inspirational values attached to them, meaning taking an approach that integrates nature and culture is a compelling way of conducting conservation (*Culture & Wetlands | Convention on Wetlands*, n.d.). Wetlands have also been frequently drained for, amongst others, urbanisation, farming, and extraction (i.e., of peat). This has been assisted by a long-held notion of wetlands as wastelands, and as undesirable, unsafe, or unproductive places. The nuanced and layered characters of wetlands means that people may get involved in wetland conservation and research for a broad range of reasons, which makes the management of these values, perspectives, and motivations all the more complex. There is also huge potential in these discussions, with the mere formulation and collection of the outcomes being able to inform future research and interventions (Hidalgo et al., 2021) and with the myriad of values and visions for the future included being decisive leverage points for realising the transformational change needed to address the climate and biodiversity crises (Flood et al., 2021). Open communication and articulation of the relationships towards wetlands, alongside the other topics mentioned in the above section on induction of organising team, will be a key determiner of the success of the project. Utilising concept maps or other visual tools is recommended.

4.3.2 Define project goals and outcomes

In order to accurately measure the progress of the project, it is important that everyone involved is clear on the goals from the outset and that they are formulated in way that allows progress to be tracked (Tweddle et al., 2012). There may be competing aims, so being clear about what balance between these will be struck is essential to ensuring a coordinated and satisfied team. Shirk and Bonney (2015) point out that this requires questioning assumptions about topics such as who may use the project data, whose goals should take priority and what success looks like. They recommend using resources such as a logic model, concept maps or results chains (Bonney and Shirk, 2015), whilst Tweddle et al. (2012) provide some questions to ask throughout the goal-setting process (Fig. 10). The idea in this stage is to create an evaluation plan that will guide the later implementation, final evaluation, and sharing of results (Phillips et al., 2014). This is important as too often evaluation is left too late to be useful (Tweddle et al., 2012).

When defining your aims, keep asking:

- What are we trying to achieve?
- Can we do this with existing resources?
- Is someone else already doing this?
- Can we work in partnership to adapt an existing project, or utilise another group's volunteers and tools?
- What type and volume of data are needed to meet the scientific aims?
- What is the spatial and temporal scope of the project?
- What defines the target participants for the project?
- What's in it for the participant and are we asking too much?
- What is our selling point?
- What will success look like and how will it be assessed?
- What is the end point of the project?

Figure 10: Questions to assist in defining the aims of the CS project (Tweddle et al., 2012)

A thorough guide to setting up an evaluation plan can be found in Phillips et al. (2014). Here some excerpts of what is required are listed (from Philipps et al., 2014 using a summative evaluation method). Firstly, it is useful to describe the project in its entirety, which includes the intended audience, deliverables, organising team, partners, stakeholders, funding sources, etc. This may also include the political, cultural, organisational, and historical context of the project. Following this, the goals can be set, which tend to be broad and abstract; these can be used to formulate targeted and tailored outcomes, which are more specific and measurable. It is useful here to use the SMART(ER) goals framework, i.e., setting goals that are specific,

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meaningful, achievable, relevant, and time-bound with the possibility for evaluation and readjustment. CS projects tend to have multiple aims (i.e., gathering data, engaging participants, meeting policy needs) which can make their management demanding (Tweddle et al., 2012). Once the goals and outcomes have been articulated, a draft logic model can be created that will be shared with relevant stakeholders.

If those involved in the CS project intend it to have policy or action implementation after the results have been determined, it is useful to identify the purposes and users of the data from the outset (Shirk and Bonney, 2015). This includes considering the required data quality, as well as other parameters such as (from Bonney and Shirk, 2015):

I. **Scale**: does data need to be taken from a single site only or across a landscape (e.g., to inform restoration efforts)?
II. **Jurisdictions**: does data need to be taken from outside the bounds of your refuge?
III. **Timeliness:** how quickly must a decision be made and what is the resulting timeframe for data collection?

Box 4.5 Implementation for wetlands

Drawing from the guidelines created by Phillips et al. (2014) and the recommendation from Bonney and Shirk (2015), this framework uses a logic model applied to wetlands. The model is based on that provided by Phillips et al. (2014), with some token examples for the categories given. In practice, it would be considerably more extensive.

Inputs	Activities	Outputs	Short term	Medium term	Long term
• Time • Organising team	• Collect / submit data • Develop data protocols...	• Deliverables (CS collected data) • Reference data for future	• Increased confidence to engage public • Peer-revieved publications	• Improved data collection skills • Informing wetland conservation activities	• Wetland policy changes

Figure 11: Logic model for citizen science and wetlands with an example answer given per section (based on Phillips et al. (2014))

4.3.3 Define project scope

The project scope step covers several factors that must be considered when thinking about the extent and range of the particular project. Therefore, this section includes level of participant engagement, level of complexity of task, and spatial and temporal scale of the project.

Participant engagement level

CS projects often feature citizens primarily in the data collection stage and ask questions which rely on basic skills, such as counting certain species of birds (Bonney et al., 2009). However, for many projects greater levels of engagement will be feasible. As such, the implications of and opportunities for participant engagement should be assessed (Shirk and Bonney, 2015). The depth of participant engagement will depend on the project needs and scale (Shirk and Bonney, 2015). One of the key considerations is whether participants will take part through opportunistic or through structured projects. The former would imply participants being able to come together across a particular research project and take part spontaneously without requiring prior training or materials, i.e., visiting a nature reserve and filling in a form with bird or butterfly sightings. This can be done anonymously and does not require a personal data collection and handling policy. If participants wish to receive information about the project results, there could be options for that, which would take different forms depending on the project (i.e., a newsletter requiring people to submit personal information – or at least their email addresses – or sharing the website to check for updates and a timeframe of when results would be expected). The latter (structured projects) refers to projects wherein volunteers sign up to a project which could take place over several days, weeks, or longer. Due to the nature of the project being longer-term, communication is required between the project organisers and the participants, which raises the need for a personal data handling strategy from the project organisers. This format could include additional training opportunities and more consistent or tailored feedback.

Research shows that policy and management outcomes are increased when participants are involved in more aspects of the project, i.e., being involved in data collection alongside tasks such as selecting sites, analysing data, and communication results (Shirk and Bonney, 2015). However, it does involve a number of extra steps and precautions. For projects wherein citizen scientists are involved in the project over a long(er) term, it is important to consider strategies and a plan for retaining participants, alongside attracting them in the first instance (Shirk and Bonney, 2015). This involves a thorough understanding and appreciating the motivations and goals of participants (Shirk and Bonney, 2015). One frequent motivation stated by participants of CS projects is the opportunity to contribute to research or discovery (Shirk and Bonney, 2015), so periodic updates from the project development team to the citizen scientists wherein their contribution is clearly explained is necessary and worthwhile. Another motivation oft given is the ability to learn something new (de Vries et al., 2019); for this, an important task could be clearly stating the learning outcomes and goals that are relevant to participants and offering an upskilling trajectory for continuous learning, i.e., moving from simple tasks to more complex ones as skills and confidence increase (Tweddle et al., 2012). Alongside understanding the psychology of involvement, there are practical questions, such as how data is handled. Greater involvement of participants requires more data on those participants, which require implementation of a personal data protocol. If the project has limited resources and is unable to manage the data of participants in a responsible manner, then perhaps lesser levels of participant engagement are called for.

Irrespective of the depth of participation, issues of reciprocity should be considered throughout the design of the project, which has both practical and ethical dimensions (Shirk and Bonney, 2015). On a practical level, participants who don’t feel listened to, or supported are unlikely to remain involved (Shirk and Bonney, 2015). On an ethical level, the power dynamics of the various actors should be borne in mind (Shirk and Bonney, 2015). CS is an opportunity to build a relationship with the participants and should be treated as such, rather than purely a public outreach tool (Shirk and Bonney, 2015).

Level of task complexity

Projects that demand higher participant skill levels are possible but should assess how much data is required to answer the research question and whether that is feasible with lesser participation as complicated projects tend to attract fewer participants (Haklay, 2013). It is also useful to consider whether extra complexity is required as simple projects are often able to address complicated questions if the project design is well conceptualised and executed (Tweddle et al., 2012), for instance, a subset of participants may be introduced who are able to conduct the more complex tasks (Haklay, 2013). Participant training and support materials can occur throughout the levels of complexity but will tend to be most pertinent with more complicated tasks. As many participants have stated their desire to learn and upskill through CS projects, this type of design also matches that motivating factor. Importantly, it is about finding the balance between reducing the complexity such that errors do not arise, whilst maintaining the ability for participants to learn and contribute in meaningful ways.

Spatial scale

CS is particularly effective at addressing questions that require a large-scale approach, particularly across large spatial scales (Pocock et al., 2014). These projects can span local, regional or (supra)national boundaries (Brouwer et al., 2019). When determining this, there are several key questions that can be asked (questions according to Brouwer et al., 2019):

- Are data gathered on one single local or regional scale sufficient to answer the project's central research question?
- Do the desired system outcomes require a local, regional, or (supra)national scale?
- What is the optimal scale based on both the research design and the desired system outcome?

Alongside those listed, another consideration is whether people may need to travel to remote sites, which may dissuade people from being involved (Pocock et al., 2014). If analysis at remote sites is required, there are ways to manage it, including partnering with an organisation like the Earthwatch Institute which is an environmental non-profit that frequently undertakes residential programmes, or through remote sensing methods which citizen scientists could also assist with.

Temporal scale

CS can also be very useful across the long-term, providing that volunteers are committed to staying involved or there are effective recruitment measures in place (Pocock et al., 2014). Effective retention processes can be difficult to design, especially where higher levels of engagement are required (Newby, 2022). As participants tend to increase or decrease their participation levels, it can be helpful to incorporate opportunities for the research design to be able to adapt during the project (Newby, 2022). Providing participant engagement remains high, CS may actually be more resilient across the long-term as changes in funding availability and grant success are not as fluctuating (Pocock et al., 2014).

There is a huge variety of temporal scales that CS projects can take, including spanning the entire temporal range of scientific inquiry, one-off measurements, and those that take days, weeks, month, or years. A question flow is provided by Brouwer et al. (2019) for considering the optimal temporal scale (Fig. 12). Alongside questioning the long-term engagement and commitment of participants, the ability of the organising team to maintain the infrastructure (i.e., websites, staff) should be considering when determining the temporal scale.

Questions

Does the research require long-term data series?

- Yes: design a long-term project, and invest in the ongoing collaboration of participants
- No: Is a once-only measurement sufficient?
- Yes: design a once-only project
- No: design a short-term project, lasting between several days to several months. The optimal length is determined by the required number of measurements in combination with the required intervals.

Figure 12: Questions to aid in determining the temporal scope of a CS project (Brouwer et al., 2019)

4.3.4 Review needs

After completing the induction, where a greater understanding of the capacity and skillsets of the organising team is acquired, and defining the project goals and scope, where insight is gained into what the project will consist of, it is useful to review the project and assess whether there are needs that still have to be met. One strategy for fulfilling needs is to broker connections, which can include those within an agency, across an agency, and/or with other institutions and programs; particularly beneficial is to do so with other actors working in the space and/or with shared or complementary goals (Shirk and Bonney, 2015).

Box 4.6 Implementation for wetlands

In terms of the skillsets required for wetland specific CS projects, it has already been noted in this paper that wetlands require an interdisciplinary approach (see Box 4.2 for more). These can be continually reviewed and assessed at this stage as well to understand whether additional expertise needs to be arranged.

There are numerous research programmes across Europe that deal with wetlands, from various angles and with differing specialities. Additionally, there are CS specific organisations that may contribute to that side. Both options provide an opportunity to broker connections with other organisations and groups and potentially alleviate any gaps in knowledge or expertise.

Table 3: List of wetlands and/or CS related organisation designed to provide some insight into how partnerships could be developed in CS projects and where expertise could be sought.

Organisation	**Expertise/speciality**		**Details**
	Wetlands	**CS**	
Wetlands International	X		Wetlands International is a science-based organisation who conducts ecological assessments, predictive models, scenario development and trend analysis. They have created a number of decision-support tools. Their aims are to assist and catalyse planning, conservation, restoration, and sustainable management practices for wetlands (Wetlands International, 2021)
BirdLife	X		BirdLife International collects and analyses data from around the world to implement the most effective and innovative conservation measures possible. This includes considerable work with Flyways, bird migratory pathways, which often include wetlands as Important Bird and Biodiversity Areas (IBAs) (*Who We Are*, n.d.)
EarthWatch Institute		x	Earthwatch connects people and scientists in order to conduct environmental research, identifying sustainable solutions to address environmental challenges. Their work helps shape environmental policies and practices (*Research Focus Areas*, n.d.)
Society of Wetland Scientists, Europe Chapter	X		The European Chapter brings together wetland scientists and other professionals from around Europe who share common interests in wetland science and management. They focus on understanding and advancing wetland science and ensuring the decision-making processes affecting wetlands are grounded in wetland science.
WaterLANDS	X	x	WaterLANDS contributes to wetland restoration across Europe and lays the foundation for protection across larger areas (*WaterLANDS: Water-based Solutions for Carbon Storage, People and Wilderness*, n.d.). They use locally tailored CS across their sites (*Citizen Science in WaterLANDS*, n.d.).

4.3.5 Identify funding and resources

CS is generally considered to offer a cost-effective approach to data collection (Pocock et al. 2014), particularly considering the quality of data that is able to be collected once the infrastructure is in place and if the research design is of good quality (Bonney et al., 2009). Tweddle et al. (2012) draw attention to the fact that whilst CS may represent a cost-effective approach, it is not free, which is reiterated by other authors (Pocock et al., 2014; Shirk and Bonney, 2015). The exact funding and resources will depend on the aims and scope of those involved (Tweddle et al., 2012) and what data shortages or community concerns are addressed (Shirk and Bonney, 2015). It will also depend on the extent and level of training provided, and the details of the particular training and supporting materials; designing and carrying out any form of training requires financial means (Brouwer et al., 2019).

For CS projects to be effective, personnel are required to direct and manage the project development, participant support, and data collection, analysis, and curation (Bonney et al., 2009; Tweddle et al., 2012). These costs can add up, e.g., CLO's CS budget exceeds 1 million USD per year (Bonney et al., 2009) while the annual support for CS project providing data for UK headline biodiversity indicators comes up approximately £100K per project per year (Pocock et al., 2014). One way of resourcing a project financially is through seeking external funding (e.g., grants, commercial sponsorship), however adequate time must be allowed for this process (Tweddle et al., 2012). Ways of resourcing non-financially include utilising open-source software (Tweddle et al., 2012) and building on previously developed resources, e.g., adapting CLO's eBird technology to collect new data or integrating and customising Google Maps (Bonney et al., 2009). With continued improvements in technology and more actors entering the CS field, this could act as a means to reduce costs of individual projects over coming years. Another possibility is to work in partnerships to divide the workload and costs and to pool resources (Pocock et al., 2014; Shirk and Bonney, 2015), as well as fill need gaps (detailed in the step above). A key question when considering the resources currently available and whether more need to be sought before commencing the project is whether there are sufficient resources to ensure that you are able to support volunteers for the entirety of the project (Pocock et al., 2014). This is an important factor when it comes to establishing connections and brokering trust with participants (Shirk and Bonney, 2015).

4.7 Implementation for wetlands

Currently funding is available through various channels, including climate change response strategies and payment for ecosystem service schemes (Ramsar, 2018). However, there is a need for further funding opportunities. This includes government funding which may support restoration and is presented as a key role for governments given the poor state of global wetlands, as well as private sector investment (Ramsar, 2018). Barbier and Burgess (2021) discuss the impact of chronic underinvestment for peatlands in their report, *Economics of Peatlands Conservation, Restoration and Sustainable Management.* This signals at a broader trend of wetland underinvestment and devaluing. CS is presented as a possible solution to bridge the lack of funding and the need for additional research (Ramsar, 2018). It should however be noted that although CS is a cost-effective method, it does not come without its own requirements for funding, investment, and resources. One way of alleviating some of these costs is to partner with other organisations and pool resources (see 4.3.4 *Review needs*)

4.3.6 Identify project participants

Participant engagement is what sets CS apart from conventional science (Shirk and Bonney, 2015) so identifying and targeting project participants is a crucial step. In recognition of the crucial involvement of participants who give their spare time to the project, it is important that this step is done early in the project design process (Brouwer et al., 2019). Recruiting participants can be simple or challenging, depending on the project goals and target audience (Bonney et al., 2009). The project team will need to consider what type of citizen scientist they wish to engage and why those people may wish to be involved. Research shows that citizen science attracts participants for a broad range of reasons, from meeting new people to gaining practical skills (Tweddle et al., 2012). Identifying the target participants is a key step as it will influence protocols, data capture systems, training approaches, and type of communication (Tweddle et al., 2012). It is useful then to think of managing participants in terms of consistency and reliability, as well as retention (Shirk and Bonney, 2015). It is a good idea to run a pilot with a smaller group and test the responses and make any adjustments before broadening out; this will ensure decent messaging and materials (Tweddle et al., 2012).

Van Noordwijk et al. (2021) pinpoint four types of CS participant group:

I. **Captive learning groups:** these groups may be school groups, informal learning groups (e.g., scouts), and museums. The idea is that educating participants is a key objective and that the participants are reached through a particular "gatekeeper", i.e., teachers. The participants may or may not have an existing interest in the topic and the level of engagement depends largely on the group leader. Tasks can grow in complexity depending on the training provided by the leader.

II. **Place-based learning groups:** participants generally become involved with these through an attachment to a particular location, through direct benefits to their life, or for social interaction. The participants may not have existing interest in the topic or in scientific research but may be prepared to invest considerable time and effort in the project. Ideally, for these projects to work successfully, participants will be involved throughout the research process (either due to being community initiated or due to trust development processes with scientists). Working with existing community groups and leaders is an effective way to build relationships.

III. **Existing interest groups**: these can best be defined according to their core aim (e.g., conservation vs. investigation) or methodology (e.g., online or in the field). Participants are likely to already have some experience in specific research topics and are likely to stay involved and devote more time to the projects. Tasks may be more complex and timeconsuming as a result. These can span extensive geographic areas and timeframes. However, the pool of participants is generally lower, and diversity can be lacking.

IV. **Mass participation:** people may take part out of curiosity in the topic, personal relevance, or interest in scientific processes. Wide sections of society can be involved as there is a low barrier for participation in terms of time commitment and existing knowledge. There is a potential for the project to have diverse participants, depending on where the project is advertised, whether it requires access to assets that are equally distributed (e.g., having a garden or not), and the tone and language used in the advertising.

Van Noordwijk et al. (2021) point out that these groups are a simplification, with variances present within the groups themselves. In any case, being aware of which group the project is targeting is a crucial step in the process. This will determine the strategy for getting participants involved, which links to *4.5.1 Promote and publicise project.*

A crucial part of the process of getting participants involved in the project is having trust between the scientists and members of the public or community. This needs to be done before embarking on the project (Chiaravalloti et al., 2021). There are different ways of doing this, including having locals and members of the community involved in the organising team or assisting in particular tasks (Liboiron, 2019). Another important step is listening to key locally trusted gatekeepers who have knowledge of conflicts and disputes in the area (Chiaravalloti et al., 2021). Fundamentally, potential, and existing power dynamics need to be acknowledged, particularly in areas where there are conservation tensions and conflicts; this is something that researchers often fail to clearly understand before starting a project, which risks compounding any existing issues (Chiaravalloti et al., 2021).

4.3.7 Design communication strategy

Developing a communication strategy will streamline the interaction with the citizen scientists (Brouwer et al., 2019). Involving experts in the fields of communication and publicity from the outset of the project will greatly assist in this process (Tweddle et al., 2012). The communication strategy should link to the goals of the project and help in realising them (Brouwer et al., 2019). It should also connect to the CS approach: if the project is contributory there may be less communication required than when the project is co-created or collaborative. Two key considerations in the communication strategy are how feedback will be given to the participants and how the interactions will be organised with and between the participants (Brouwer et al., 2019).

Feedback

Although providing feedback to participants is important throughout the project, it is worth taking time to develop a strategy for how exactly this will be done before participants are recruited. This feedback is crucial for ensuring that they remain satisfied and committed throughout the project (Brouwer et al., 2019). This will include providing insight into how useful their contribution was and how the data they collected fits into the wider picture (Brouwer et al., 2019). Different moments of the project will call for different forms of feedback, i.e., after participants have submitted their data, it might be beneficial to provide rapid feedback in the form of an online map or chart or once analysis has been conducted, a more thorough summary may be given. This depends on the infrastructure available to the project and what the objectives and circumstances are (Brouwer et al., 2019)

Communication channels

Communication with participants can take various forms, including organising formal and informal group meetings, workshops, and trainings, creating an online platform for communication and information sharing, via email, and more (Brouwer et al., 2019). Some of these options may allow participants to communicate with one another as well as with the organisers. If the aim focuses on influencing individual actions this may not be required, but where the project aims to create a community network, this may be required (Brouwer et al., 2019). Data sharing regulations need to be considered here, with a consensus letter presenting one option for how to manage the communication of data management and request permission for any sharing etc. (Brouwer et al., 2019).

4.4 Development stage

4.4.1 Design research scheme or survey

When designing the project scheme, the data requirements (i.e., amount and type (Brouwer et al., 2019) and available technology need to be considered (Tweddle et al., 2012), which relates to other components of the process, including the research question and funding opportunities. Particularly important to consider is the scope *(4.3.3)*, which in this framework is categorised under *4.3 Project design*. Articulating the research scheme involves responding to the decision made during the scoping stage, i.e., the participant engagement level, complexity level, and the spatial and temporal scales need to be. Some key considerations when designing the research scheme are (from Tweddle et al., 2012):

I. What is being asked of the participants under this research design? How will they complete the tasks?
II. What equipment is required and how will participants acquire it?
III. Does data need to be collected in the same manner each time? Can the method be standardised?
IV. How will the sites be determined, i.e., will they be allocated, or can participants choose them?
V. Are there any additional health and safety concerns beyond what has been articulated already in the risk assessment (*5.2.3g*)?
VI. What will happen in the event of technology failing, variable mobile signals, or other potentialities which may have been covered in the risk assessment (*5.2.3g)?*
VII. What information will need to be included in the supporting materials and what is the most appropriate format?
VIII. Is training required, and will that happen centrally, digitally or in another manner?

IX. Does the research scheme support the goals of the participants? Are there additional measures that need to be taken to ensure this?
X. What form of technology will be best for the research scheme? How will it appeal to the participants?

Brouwer et al. (2019) identify five distinctive research designs, with the primary distinction between them being the temporal and spatial scales at which they operate. These are (from Brouwer et al., 2019):

I. **Experimental:** testing of dependent and independent variables in a semi-controlled, randomised setting. In CS this may be used to test hypotheses on a large, coordinated scale. Examples of this design may be found in Schröter et al. (2017).
II. **Cross-sectional or survey:** collecting a small amount of data from a large sample of people in a standardised manner. In CS this may be used in combination with monitoring efforts or as part of participant surveying whereby participants evaluate their desired outcomes and goals.
III. **Longitudinal:** performing monitoring activities multiple times, e.g., retaking a sample or repeating a survey. In CS this may be used through registration of observations over long periods of time.
IV. **Case study:** studying and analysing one case intensively. In CS this may be used to analyse specific local issues and are linked to various desired outcomes such as community building.
V. **Comparative:** carrying out two or more studies with one of the other designs at the same time. This allows for comparison over large spatial areas.

A combination of these research designs may also be applied (Brouwer et al., 2019).

4.4.2 Develop data protocols

This step involves both ensuring data is of a high quality as well as developing data management strategies for CS projects that adhere to rules and regulations regarding data privacy and management. It also covers how data will be inputted by participants. These three aspects are detailed below.

Data quality

Data quality is one of the major concerns that comes up with CS (Shirk and Bonney, 2015), and is particularly emphasised by professional scientists who may be sceptical and distrustful (Balázs et al., 2021). One of the key elements of concern with data quality is that different projects and stakeholders aspire to different levels of data accuracy (Balázs et al., 2021). Multiple authors point to ways to alleviate this concern, i.e., through realistic goal setting, careful design, training materials and support provided (Shirk and Bonney, 2015; Tweddle et al., 2012; Balázs et al., 2021). Bonney et al. (2009) make the case that accurate data depends on three things:

I. **Providing clear data collection protocols** which inform participants when, where, and how the data should be collected. These protocols should be engaging, easy to perform, and explained in a straightforward manner. The authors argue that protocols should be pilot tested. This is particularly relevant for projects that will involve a large participant demographic.
II. **Providing simple and logical data forms** that are both easy to understand and easy to fill in. Forms should be carefully formulated to ensure questions of data quality are addressed, i.e., eBird data forms ask participants to record whether they are reporting all of the species that were observed at a given moment or location; this can be used by analysts to better understand and explain the data. Filters (i.e., geographic ranges of bird species) can also be implemented in the form, so that any breaches can be investigated further, or participants can be asked to double check their observations.
III. **Providing support for participants** to understand how to follow protocols and submit information. These materials can include identification guides, posters, manuals, videos, and FAQ lists. An interactive quiz is one method used by CLO which rewards correct answers with a certificate to motivate participants.

Regarding data collection protocols (1 in the list above (Bonney et al., 2009)), Shirky and Bonney (2015) recommend making a Quality Assurance Project Plan (QAPP). A QAPP is a written document outlining the procedures used in a given monitoring project to ensure that the data collected and analysed meets project requirements and the requirements of the US Environmental Protection Agency (EPA). The idea is that building the procedures from the beginning helps ensure that the quality needs will be met. Steps that may be included are equipment calibration, training, and protocols (Shirk and Bonney, 2015). Two methods which can serve to reduce error rates in the data are validation and verification (Tweddle et al., 2012). Validation is an automated process to check if the data meets certain criteria (Tweddle et al., 2012). If not, a secondary measure could be taken, verification, whereby additional, usually manual, data checks occur. Photographs, sending samples, or multiple measurements from the site are a few verification tools (Tweddle et al., 2012). Additional people could be brought into this step, thus crowdsourcing where participants are checking each other’s data could be built into the research design. Brouwer et al. (2019) recommend checking if there are research standards available for guiding and standardising the data collection, which could ensure comparability with other studies.

Regarding providing support to participants (3 in the list above (Bonney et al., 2009)), communication is key once again, as are proper training opportunities (Brouwer et al., 2019). Shirk and Bonney (2015) describe how the scientific value of citizen science can be increased by defining the data needs and connecting with data users from the start while Brouwer et al. (2019) state that sampling bias is often related to the training of participants. Alongside this, an awareness of the interests and capabilities of volunteers in terms of skills, interests and capacities contributes towards more scientifically robust data (Shirk and Bonney, 2015). Variation in data quality, including that between participants, is fairly common but can be handled such that it is passes quality assurance (Pocock et al.

2014), i.e., it may be modelled statistically and taken into account when undertaking analysis (Tweddle et al., 2012). In order to do so, observation of participants and identification of types of errors being made is useful. This also allows to assess where biases may lie so appropriate measures can be taken or special attention can be given to them. Some biases that have been found are a tendency to overreport and underreport certain species and a reluctance to enter data when only common species are seen, or no species are found (Bonney et al., 2009). Bias is considered the most likely error; this can be both a systematic error (i.e., the tendency to overestimate) or individual (i.e., level of experience) (Pocock et al., 2014). People are more likely to record the presence of something than the absence, which may create systematic biases in the data. This will lead to areas with a high population concentration or level of outdoor activity (i.e., national park) being well covered by CS (Haklay, 2013). There is also a temporal aspect to bias, with summer months, weekends, and daytime being more popular times for data collection (Haklay, 2013). Special planning and motivation schemes can help reduce the impact of these biases (Haklay, 2013). Bias should also be quantified and explicitly accounted for in the data (Pocock et al., 2014). Random error is another form of bias which will increase the 'noise' in the data, making it more difficult to accurately read the data (Pocock et al., 2014). It is important to bear in mind that the data are essentially heterogeneous and will vary according to volunteer numbers and levels of knowledge (Haklay, 2013). Guidance in the form of developed protocols and logistics can enhance the credibility of delivered data (Brouwer et al., 2019).

Shirk and Bonney (2015) point out that quality as a term can be defined in various ways, so more helpful and productive questioning may be:

I. What level of data quality do I need to address these goals?
II. What can I do to improve data quality?
III. What can I learn from this data given its level of accuracy or precision?

Meanwhile, Tweddle et al. (2012) recommend trying to maximise the value of the data by using accepted data and metadata standards.

Data storage and management

Another important component of data protocol development is planning how data will be managed, which includes storing and sharing (Shirk and Bonney, 2015) and ensuring that confidentiality of data is safeguarded (Phillips et al., 2014). Data management for CS, whilst similar to data management for other research activities, has some key differences due to the involvement of the public (Wiggins et al., 2013). This involvement means that CS projects must carefully balance trade-offs in designing protocols and systems that support participation (Wiggins et al., 2013). There tends to be a trade-off between the number of participants in a project and the complexity of the protocols (Tweddle et al., 2012). Shirk and Bonney identify two key differences with CS project data management: (1) the data protocols must also consider how to manage data about participants, including in instances where they may be anonymous, their data collection skills may be unknown, and their familiarity with data may vary widely (Wiggins et al., 2013) and (2) the data needs to be more accessible and useful for participants and partners. Adding to this, Wiggins et al. (2013) mention the size of the project development team in CS projects and the number of individuals interacting with the project data. Indeed, one of the key advantages outlined in this study of CS is the ability to generate large datasets; naturally this presents challenges regarding data management. Some form of infrastructure is thus required to manage the data, which may be high or low tech (Shirk and Bonney, 2015). This infrastructure needs to take into account data protection legislation (e.g., through consulting organisational or institutional guidelines (Wiggins et al., 2013) if storing personal data and needs to consider the long-term storage of data (Tweddle et al., 2012). It is likely advantageous to consider existing infrastructure, in particular for small-scale or local projects. Over time, infrastructure, including technology platforms and tools, has been developed for other CS projects with an implicit or explicit intention to be used for other projects. Shirk and Bonney (2015) provide some examples that cover a wide range of infrastructural needs: platforms for app development (e.g., Sapelli), sensor design (e.g., Public Lab), mapping (e.g., collaborative geomatics), and overall data and volunteer management (CitSci.og). There is also the initiative, which acts as a resource for planning data management itself (Shirk and Bonney, 2015), which may be used as a foundation, or pathway, to arranging the other needs. The data life cycle model, created by DataONE (Fig.13), demonstrates the various processes involved in data management. For more information about each step, readers are directed to the Data Management Guide for Public Participation in Scientific Research (Wiggins et al. 2013) where each stage is also discussed as it relates to citizen science. There will be variances across CS projects regarding what data is being collected and stored and for what purpose. Phillips et al. (2014) recommend documenting the following as a first step to creating a data management plan:

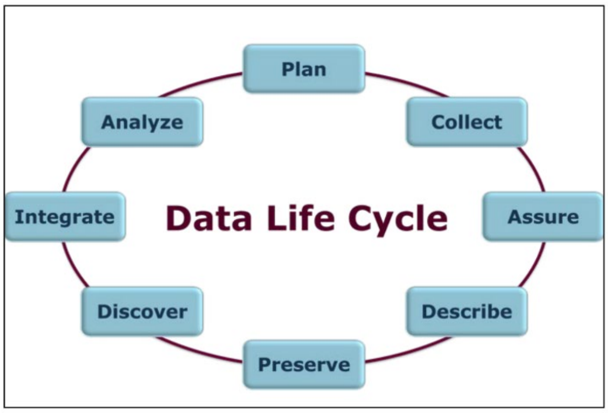

Figure 13: The data life cycle model, created by DataONE to demonstrate the various processes involved in data management (Wiggins et al., 2013)

I. What is the source of the data?
II. Who will be collecting the data?
III. Where will the data be stored and archived?
IV. Who will be in charge of data analysis?
V. Who else will have access to the data?
VI. Any changes made to instruments, questions, evaluation design, or procedures.

Data inputting

It is useful in this step to determine how participants will share their data with the project team (Brouwer et al., 2019). This might be in the form of sharing measurement results in numerical form or imagery via a dedicated website or app (Brouwer et al., 2019). It may also include open, multiple-choice, or Likert-scale questions (Brouwer et al., 2019). It is important to conduct a thorough check of the data inputting methods. This includes checking for and avoiding any biases in questions, arising through, e.g., formatting, use of technical jargon or faulty scales (Brouwer et al., 2019). The effort level should also be considered, e.g., excluding very long questionnaires or using (too many) open questions (Brouwer et al., 2019).

4.4.3 Decide on appropriate tools and methods

The exact tools and methods used in a particular CS project depends on the scope and research design. Possible tools include, but are not limited to (from Brouwer et al., 2019):

I. Observations, including the time and location of recording;
II. Images, sounds, or video recordings;
III. Physical samples (e.g., water samples);
IV. Sensory data (e.g., temperature or radiation);
V. Classifying pre-collected data (i.e., crowdsourcing tasks such as pattern recognition)

Simplicity is often the key to the success of mass participation in CS projects (Pocock et al., 2014). Often contributions that do not require high levels of time investment or expertise will have relatively larger numbers of participants, whereas with a more complex protocol, the number of participants is likely to decrease, although the data value may increase (Pocock et al., 2014). When using a complex protocol, it should be thoroughly tested and should be clearly explained to participants (Pocock et al., 2014). Understanding the motivation of the participants is key here, as they may not wish to devote too much time to a project, especially when acting as a volunteer, however, some may be motivated by learning new skills so having opportunities to be involved in complex protocols may be a drawcard for some. It is useful here to assess the expertise level of participants and consider having different levels of contribution depending on the experience level of the participant (Brouwer et al., 2019). The ideal balance provides an intellectual challenge to participants but does not overestimate what contribution they are able to make (Brouwer et al., 2019).

A lot of CS projects develop or source low-cost monitoring and data submission tools (e.g., Liboiron, 2019; Starkey et al., 2017). The idea behind doing so is to encourage long-term monitoring beyond the lifetime of the project itself and for the citizen scientists to physically observe and learn about the water environment and weather themselves rather than relying on automatic sensors (Starkey et al., 2017). For instance, Starkey et al. (2017) explain their choice of low-cost monitoring and data submission tools as being designed for encouraging long-term monitoring that went beyond the lifetime of the project itself and for encouraging citizen scientists to physically observe and learn about the weather and water environments. For this reason, they did not distribute automatic sensors (Starkey et al., 2017). Liboiron (2019) details the guidelines used in the Civic Laboratory for Environmental Action Research (CLEAR) regarding instrument development. These include (from Liboiron, 2019):

I. Using place-based design;
II. Made of locally accessible materials;
III. No need for electricity to run or be built;
IV. Cost less than $50 to make;

V. Can be built and used by people outside of academia;
VI. Use of open-source licensing and publishing instructions online;
VII. Able to be repaired with local materials.

These guidelines are specific to their work in Newfoundland and Labrador, Canada, however, many of the principles they outline could be used by other CS projects, depending on the nature of the research question and research design.

Box 4.8 Implementation for wetlands

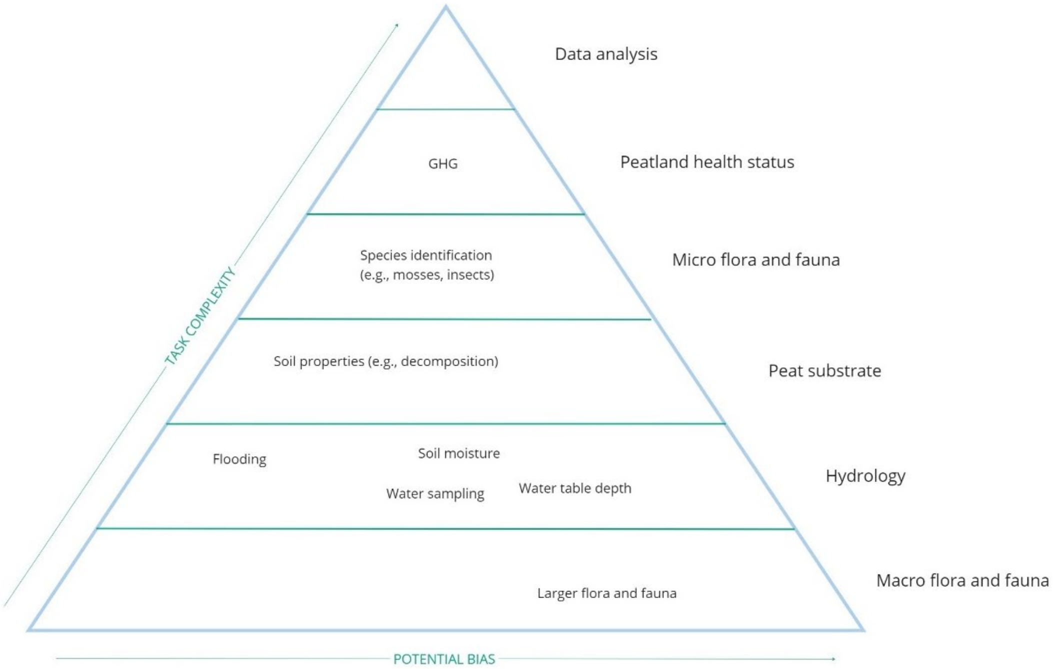

Figure 14: Interpretation of how the task complexity and potential bias matches with research focus areas and tasks for studying wetlands

For wetlands, there are a myriad of questions that could be pursued, focuses that could be made, and tools that could be utilised. There are different levels of complexity associated with these, as well as varying levels of bias that a particular method may engender. These should both be considered when determining the appropriate choice. Fig.14 demonstrates an interpretation of how task complexity and bias may combine with CS research for wetlands. The tasks go up in difficulty with a shift to the right indicating greater potential bias.

The following provides some rationale behind the placement of different tasks:

- ***Macro flora and fauna*** is considered the easiest option regarding complexity as species can be more readily identified. Furthermore, they are easier to spot and documentation (i.e., photos) may be made. The bias present in the task, *larger flora, and fauna*, is based on the tendency of people to monitor areas with larger populations more frequently (Fraisl et al., 2022). There is also a temporal bias present in that people will tend to monitor in higher numbers during daytime hours and weekends (Fraisl et al., 2022).
- ***Hydrology*** is considered the second easiest option as there are standardised protocols for many of the tasks and set equipment, for which videos and other guidelines can be made. *Water table depth* is considered more susceptible to bias based on the effect weather has on participant behaviour across both time and space, meaning that higher water table depths due to more precipitation may have less representation. *Flooding* is considered less affected by bias as the general methods for assessing, e.g., flood hazard risk can be more easily verified or compared with other data, either collected by volunteers or through other means, e.g., checking rainfall measurements across similar sites or land use change using multiple methods, including municipal maps, GIS, and remote observation. These two are less affected by spatial and temporal bias as there are multiple means of gathering the data. *Soil moisture* and *water sampling* are placed between these two, with there being an impact due to spatial and temporal bias. The latter may also have a bias in the inconsistent use of technical tools.
- ***Peat substrate*** is located in the middle in terms of complexity, with some training and expertise needed to test and interpret the *soil properties*. Bias is present primarily in identification or observation mistakes; however, photos and samples can be taken to reduce this in later steps. This may have an added bias in the loss or damage of the physical data, however.
- ***Micro flora and fauna*** is listed as more complex than macro flora and fauna as species identification itself is more difficult. This measurement is affected by spatial bias in terms of where participants are sampling, however, photos can be taken of the species, making eliminating errors down the line easier.
- ***Peatland health status*** is the most complex of observational and data collection aspects of this scheme. This is because it requires a broader understanding of ecosystem and landscape dynamics and utilises more advanced technology and tools, including manual chambers for *GHG.* The bias is relatively lower when the task is standardised and repetitive, and guidelines and training can be geared towards ensuring this task is understood, including testing of the ability of participants.
- ***Data analysis*** is the most difficult in terms of complexity, as it requires more expertise and training in different techniques. As such, bias here is present in a possible lack of knowledge and expertise, particularly as CS may require complex analytical tools to correct for other biases or lack of representation in the data.

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It is important to note though that there are multiple types of bias, and equally many ways of dealing with and reducing the level of bias present in the data (Table 4). Therefore, the bias level of the above tasks should be understood as a cursory insight into how this may play out.

Table 4: Possible biases present in CS methods (recreated from Fraisl et al., 2022)

Concerns related to	Examples of issues and concerns related to data quality	Mitigation procedure
Skills of the participants	Inconsistent application of the protocol, including physical loss of data	Training of participants before and during the project; adapted guidelines; expert control and filtering of the data; community-based validation; automatic filtering and big data approaches; evaluation of participants'' skills
	Inconsistent use of technical tools	
	Identification and translation mistakes	
	Observation, identification, or systematic sampling bias (e.g., cryptic species surveys)	Specific participant training or testing; targeted expert validation
Habits of participants	Unrepresentative sampling effort	Structured protocols with prescribed sampling in space and time; data filtering and correction factors, model-based integration
	Bias or lack of neutrality	Mutual checking by professional scientists and participants on possible conflicts of interest; triangulation across communities, participants, and methods

4.4.4 Create plan for data analysis

Planning the data analysis before moving onto the data collection is vital for ensuring the required data is gathered (Tweddle et al., 2012). One of the important considerations is whether data analysis will occur continuously throughout the project or whether it will only be conducted at the end of the project (Tweddle et al., 2012). Irrespective of which option is chosen, there are some general steps that will need to be included in the data analysis plan. This includes (from Tweddle et al., 2012)

I. **Data cleaning:** This is the process whereby spurious results are removed or investigated. Having a plan for how this will happen at the start of the project is essential. It may also occur earlier through the validation and verification processes.
II. **Visualising the data:** Before doing the statistical analysis, it's useful to visualise the data and produce a range of summary statistics that provide general insight into the results.
III. **Statistical analysis**: The statistical analysis will depend on the type of data collected. Simple analysis may occur first, followed by more thorough analyses later
IV. **Data quality assessment:** Alongside the data, confidence limits and verification levels should be documented, as with other scientific methods. The quality of data should be clearly started, as to increase its use-value for scientists and policymakers.
V. **Interpretation:** Once the data has been analysed, you can compare the results to the hypotheses and project aims.
VI. **Qualitative analysis:** Most likely there was some type of qualitative data gathered from participants as well. This could be in the form of feedback or comments. It is useful to assess these as part of the overall evaluation processes and to improve projects in the future.

Although this plan may be adapted as the process continues, having the plan arranged from the outset will set the project off on a good track.

4.4.5 Test and modify protocols

Testing the various protocols and materials is a crucial step to ensure that they are fit for purpose (Tweddle et al., 2012; Phillips et al., 2014). Where possible, it is advised to adopt standardised and vetted protocols used by others, albeit with customisations made based on local or regional conditions (Shirk and Bonney, 2015). This may be possible by using a tiered system of a nationally tested protocol paired with an additional locally- or regionally tailored protocol (Shirk and Bonney, 2015). In any case, it remains useful to test and modify to the particular context; this offers an opportunity to counter any assumptions that may have been made regarding what appeals to different people, what kind language is appropriate, and whether instructions are clear or not (Tweddle et al., 2012). To get the best understanding of how the protocols will work in practice, having the potential participants themselves test them is best (Tweddle et al., 2012). This is an iterative process that involves assessing where participants go wrong and what questions are raised, adjusting accordingly and then testing and refining again (Tweddle et al., 2012). It may involve radical changes as well as adjustments with the ultimate aim being to maximise the clarity of materials and the quality of data (Tweddle et al., 2012). Completing this stage before data collection begins will help to minimise observation error, increasing the credibility of the results (Phillips et al., 2014).

Box 4.9 Implementation for wetlands

The majority of CS projects with wetlands will entail participants being out on wetland conducting various forms of field research. As it is outdoors and a changeable environment, it is a good idea to test protocols in multiple conditions to ensure they work optimally no matter what conditions are faced by the participants.

4.4.6 Develop supporting materials

Once a finalised (albeit with changes that may still need to be made and an understanding of the process as being iterative) data protocol is made, the supporting materials to instruct participants should be made. This is critical for participants to successfully take part in the project. For structured projects, this may be a research kit that consists of background reading, project instructions, and support materials (i.e., species identification posters, instructions for building anything required, CDs of ecological soundscapes) (Bonney et al., 2009). This could be physically sent to participants or available online. For opportunistic projects, this will be condensed information in a poster or brochure form at the site itself that perhaps has a link to additional information via a website. In either case, clear, user-friendly supporting materials are a key component of securing reliable and accurate data (Brouwer et al., 2019). This will provide the necessary support for participants to carry out their tasks (Brouwer et al., 2019). The following elements may be included (from Brouwer et al., 2019):

I. Information on the purpose of the sampling;
II. An overview of the tools and equipment needed or provided;
III. Information on where and when sampling should occur;
IV. Description of the potential risks involved and how to limit them;
V. Overview of the step to be taken;
VI. Contact information in case of an error or issue when sampling.

Another aspect of the supporting materials is a clear data synopsis. It is important from the outset for participants to be informed about how the data will be generated, how it will be made available, and how it will be used (Shirk and Bonney, 2015).

Box 4.10 Implementation for wetlands

As wetlands have traditionally had a perception of being wastelands, the supporting materials are a good opportunity to highlight the importance of wetlands, beyond the direct scope of the citizen science project. This should be in a clearly separate section of the materials, to avoid any confusion or convolution of the project descriptions and instructions. It is a bonus when this can be in the form of video, infographics, photos, and other such mediums that are able to relay the significance of peatlands and allow people to gain new perspectives on these ecosystems.

4.4.7 Create logistics plan

The logistics plan will detail the key moments in the data collection and analysis, record training moments and other key dates, and cover other practical considerations, including how to deliver the manual, toolkits, or specific requirements to the participants (Brouwer et al., 2019). In co-created projects, citizen scientists might be included in the development of this plan (Brouwer et al., 2019).

Part of this step is a risk assessment, which needs to be conducted to provide insight into the potential risk and hazards associated with the carrying out of the data collection (Brouwer et al., 2019). If there are any risks involved in participation, these need to be carefully communicated with participants (Brouwer et al., 2019). Risks can be both physical and digital, with the former referring to any hazards coming with conducting field research or other forms of research, and latter consisting primarily of data risks and rights. For the former, adequate training and guidelines are one means of reducing the risk; these will include how to limit potential risk and provide any necessary warnings (Brouwer et al., 2019). For the latter, one way of managing this is to design a consensus letter, which will provide information on how the data will be used and how intellectual property rights are being considered and handled (Brouwer et al., 2019).

4.5 Execution stage

4.5.1 Promote and publicise project

Sufficient time should be dedicated to planning the publicising and promotion of the CS project as it is critical to the successful recruitment of participants (Tweddle et al., 2012). The recruitment of participants will vary in difficulty depending on the goals and target audience of the project (Bonney et al., 2009) as well as the size of participant pool required for carrying out the project (Tweddle et al., 2012). There are four different recruitment strategies detailed by Brouwer et al. (2019), building on the work by West and Pateman (2016) and Brouwer and Hessels (2019). These four strategies are (from Bouwer et al., 2019):

I. **Word-of-mouth**: existing participants acts as advocates for the project to potential new participants;

II. **Use of third-party organisations** (e.g., volunteering agencies or educational establishments): the organisation promotes the project. This intentional partnering, developed during the project development stage, may result in more participation that would occur otherwise (Bonney et al., 2009);

III. **Scattergun:** the project is advertised to large numbers of people but not a particular demographic (e.g., using social media, press releases, radio coverage);

IV. **Targeted invitations**: personal invitations are sent to a random sample of the population.

To this one can also add use of existing network, which overlaps somewhat with the word-of-mouth strategy. Where members of the organising team already have a following or existing membership, this audience can be targeted through email newsletters or social media (Tweddle et al., 2012). It is also possible to host a launch event where followers could be invited and face-to-face promotion can happen, or to join and promote at existing events (Tweddle et al., 2012) which may lessen the load on the organising team. The promotion will differ according to who is being targeted as well as what media is being used (Tweddle et al., 2012). If the project is aimed at the general public, brochures, flyers, presentations, press releases and other associated PR may be good techniques; if a project has been developed for a specific audience, then naturally the recruitment materials should be targeted to that audience (Bonney et al., 2009). In either case, stating who the target audience is (i.e., a particular age-group) is a useful addition to promotion materials.

Depending on the identification of desired project participants (*4.3.6 Identify project participants*), different promotion strategies will be pursued. Participants can be recruited into mass participation projects, where it may be widely promoted for anyone anywhere to take part, or projects can seek to involve expert volunteers who are committed to making observations and gathering sample that provide long-term surveillance and data (Pocock et al., 2014). It is even possible to engage people indirectly, i.e., through harvesting social media for information (Pocock et al., 2014). If a project is designed for specific audiences, the recruitment materials should naturally be tailored towards those audiences and should take into account specificities in terms of approach as well as content, i.e., providing support materials may not be enough in some instances and partnerships may be a more fruitful option (Bonney et al., 2009). If the project is designed for the general public, a variety of techniques may be employed, including press releases, advertisements, public service announcements, magazine articles, flyers, and presentations (Bonney et al., 2009). The messaging is crucial here as what works well for one group of participants may not be as effective with another group (i.e., naturalists and school children) (Tweddle et al., 2012).

If projects are relying on opportunistic participation, then the emphasis is on the posters and materials that participants will come across. These should be attention-grabbing, informative, and engaging. They need to be standalone materials, with the possibility of using a QR code or website link to find out more information if desired. In this case, the placement of information is also a really key aspect, ensuring that people are able to easily find the promotional materials whilst they are going about other activities. As such, in wetland sites with boardwalks, informational boards should be in close vicinity, and additional information can be given at informational centres and ticket offices.

4.5.2 Induction of project participants

This step is analogous to the induction of the organising team in that it involves deliberation of the motivations, expectations, needs, and responsibilities of those involved. It is, however, tailored to information and insights that the organising team need to have about the project participants.

The motivations of participants are a key component of a citizen science design as the sustainability of CS projects is dependent on continued public participation (de Vries et al., 2019). The reasons for (continued) involvement vary between people and can change over time (Pocock et al., 2014). According to de Vries et al. (2019) who conducted a review of the preferences of participants in CS projects, important factors for involvement include:

I. Interest in the project's topics
II. Interest in science in general
III. Desire to learn something new
IV. Desire to contribute to scientific knowledge

Some may also be motivated by a progression of knowledge or expertise (Pocock et al., 2014). Motivations may then be personal, but they might also be broader. Brouwer et al. (2019) distinguish between desired individual outcomes, desired scientific outcomes, and desired system outcomes (also called socio-ecological and economic by van Noordwijk et al., 2021). In terms of individual outcomes, participants commonly state fulfilling educational purposes and fostering social learning (Brouwer et al., 2019). Furthermore, it is also linked to an increased sense of agency and engagement with participants' direct environment, both social and physical (Brouwer et al., 2019). Scientific outcomes can consist of the advancement of scientific understanding of a particular object of study (Brouwer et al., 2019). This can include collecting scientific data, including specific local data, and creating and collecting a large-scale database (Brouwer et al., 2019). The impacts of greater understanding could have direct outcomes for the specific object of study as well as direct impacts on other natural phenomena or environments (Brouwer et al., 2019). System outcomes acknowledge that CS also generates impacts on the broader socio-ecological system. These outcomes could include (from Brouwer et al., 2019):

I. Strengthening the social capital of a community due to the interactions fostered between community members and agencies and scientists;
II. Increased trust in institutions and scientific processes due to these enhanced interactions;
III. Higher societal acceptance of results due to the increased scientific literacy of society;
IV. Greater political participation and interest in policy making, and;
V. Increased engagement in taking action within local environments

In terms of expectations, it can be that there are tensions between the motivations of participants and the goals of the organisers (Pocock et al., 2014). Participants may expect that local actions may be taken resulting from their data and contribution, but this may not occur for a range of reasons (Pocock et al., 2014). Thus, it is vital to have open and clear communication between organisers and participants.

The same goes for discussions around needs and responsibilities. If participants have specific needs that can be accommodated by the project, it can be incorporated into the training step. For this the participants need to be made aware that it is an option, and the organisers need to be aware of gaps in knowledge that may be dealt with through extra training. There are specific responsibilities that need to be articulated, e.g., responsible use of equipment, the requirement to collect data at specific days, times or sites, and the need to upload data in a particular way. Some projects write job descriptions for the project participants, wherein they are designated certain responsibilities, including time commitments and quality standards (Shirk and Bonney, 2015). These can be used to recruit participants and then be available for participants to refer back to throughout the project. Even if not done through a job description format, it is important that expectations and requirements are clearly communicated, and that they are reasonable and respect the time and efforts of the participant (Shirk and Bonney, 2015). The organisers should clearly express the responsibilities of the participants to them and deal with any questions or concerns. In return, the organisers have the responsibility to ensure that participants feel informed, safe, and ready to take up the tasks.

4.5.3 Train participants

Providing training to participants is an important component of CS projects, allowing to reduce the risks as well as increase the credibility of collected data (Brouwer et al., 2019). However, before assuming the extent of training needed, it is advantageous to consider that many participants may bring existing skills (Shirk and Bonney, 2015). These may be amateur expertise (i.e., in species identification), traditional ecological knowledge (TEK), or ancillary skills in social media or community organising (Shirk and Bonney, 2015). Recognising these skills is important from an inclusionary perspective as it acknowledges the participants beyond simply being a source of free labour (Shirk and Bonney, 2015) as well as being a useful foundation to build further capacity, i.e., providing basic training alongside more advanced training where suitable. After evaluating the initial level of participants, additional training can be utilised to best effect. This ensures that participants are equipped with the knowledge and skills needed for the specific project. It also speaks to one of the common motivating factors of involvement given by participants, which is to upskill and learn something new (de Vries et al., 2019). Training and acknowledgement of existing skills may both be used to instil confidence in the participants, which is an important component (Bonney et al., 2009); a lack of confidence in the results gathered has been attributed to participants not uploading their data (Tweddle et al., 2012).

Alongside being tailored to the training required by participants, the training should be receptive of the skill level needed to meet the data requirements (Shirk and Bonney, 2015). It also needs to consider the scale of the project, i.e., if it is a national-scale project, the training may be best in the form of videos or digital manuals, whereas local projects may be able to run in-person training sessions (Shirk and Bonney, 2015). If projects are carried out by groups, then further training may be used, to ensure that group leaders have the skills to guide and provide information to participants of their group (Bonney et al., 2009); this is then a train-the-trainer type of model, which can lead to more people being able to be engaged and informed through the diffuse nature of the model.

There are various forms that training can take, including face-to-face training sessions, online courses, quizzes, readings; they can also occur on a one-off basis or multiple times (Brouwer et al., 2019). It is quite useful to incorporate several of these options into the training plan. This allows for different learning styles and capacities (i.e., ability to attend in person on a particular date or comfort level with different software); it also allows for consolidation of learnings, i.e., people can read through or watch the training materials and then test themselves with a quiz. The particular form should take into account the specific of the project. One example is the project design, including the complexity of the protocol, i.e., the greater the level of complexity, the more advisable it would be to have an in-person or video training to improve understanding (Brouwer et al., 2019). Step-by-step guides would also help in this case (Brouwer et al., 2019). Another is the CS approach chosen, i.e., if the project is co-created, there is likely a bigger need for intense training and preparation of participants (Brouwer et al., 2019). Contributory and collaborative projects may require more limited training (Brouwer et al., 2019). With appropriate training (alongside protocols and oversight), participants can produce similar results to scientists about the status of natural resources (Newby, 2022).

As well as protocol specific information, training guides and materials can also inform participants who to contact for more information, how to stay involved, and how to access further training materials (Brouwer et al., 2019).

4.5.4 Data collection

Data collection is the most common activity included in CS projects, based on that fact that the protocols are less complex, measurements can be replicated, and large areas may be covered. This step involves the carrying out of the data collection, which responds to the research question, adheres to the research design, and utilises the tools and methods set out in the earlier stages of the framework proceedings. Thus, this step acts as a culmination of those steps and the foundation to build the later steps.

Acknowledging the concerns about data quality, it is a good idea to note where data quality may be improved continuously throughout the project. There are several opportunities during the data collection phase to enlarge credibility (Brouwer et al., 2019). In long-term projects, participants can be trained throughout, allowing constant improvement of data collection skills, and encouraging consistent involvement (Brouwer et al., 2019). Experts, participants, or external parties could be asked to verse the data collection process and point out any errors (Brouwer et al., 2019). Other validation methods include incorporating control measurements by professionals or asking for a confirmation of an observation, e.g., a photo (Brouwer et al., 2019). Technological aids could also be utilised to support data validation and verification as well as make the data collection easier, e.g., automatic location identification (Brouwer et al., 2019).

4.5.5 Accept data and provide rapid feedback

The information collected by the citizen scientists, needs to be accepted, edited (where appropriate) and made available for analysis by both professional scientists and the public (Bonney et al., 2009). CS participants often express the desire to receive rapid feedback, with the more instantaneous the feedback the better (Tweddle et al., 2012). One way to allow this could be to use technological aids that would ease the trade-off between feedback time and quality control (Brouwer et al., 2019). Data can be shared as graphs, maps, histograms, or other visualisations. Apps are a particularly useful tool here as data can be both inputted and viewed through one location. Data visualisation and analysis tools, which allow and encourage participants to manipulate and study data could act as one of the most educational aspects of the CS process (de Vries et al., 2017; Bonney et al., 2009). Bonney et al. (2009) report that once eBird upgraded the features available the number of individuals submitting data almost tripled; the upgrades allowed participants to track their own observations and explore how their results compared with others. Evidently, the engagement with the data itself represents a real plus for participants. The form of data acceptance and acknowledgement will differ depending on the budget, with real time results being more expensive than some other options, such as email - either personal or automated (Tweddle et al., 2012). Phone messaging is another option that can be automated, but it is an expensive one (Tweddle et al., 2012).

When accepting the data there is also a good opportunity to thank participants for their contribution and for taking part, which increases their sense of value to the project and encourages continued engagement (Tweddle et al., 2012). It is best to strike a balance between offering feedback on the data and contribution whilst not swamping participants with information and outreach (Tweddle et al., 2012).

4.6 Data analysis and reporting

4.6.1 Complete data analysis

This step will see the project carry out the data analysis plan that was created in step *4.4.4 Create plan for data analysis*. Here a step-by-step guide was made for the data analysis. In this section, some challenges and specifics of data analysis are discussed.

As with other previous steps, there are several control mechanisms that can be incorporated at this stage to filter out any of the errors during data collection (Brouwer et al., 2019). One way of doing so is through statistical control which could identify any errors and assess the completeness of the dataset (Brouwer et al., 2019). If the data collection protocol is standardised, this step can be strengthened further, allowing for broader statistical control (Brouwer et al., 2019). Data with certain characteristics can also be filtered out, e.g., those collected by first year participants, by those who have only submitted on an irregular basis, or those who have submitted reports containing errors (Brouwer et al., 2019). A cross-comparison with data collected by professionals, i.e., from previous studies, could also be used to check the validity of the data (Brouwer et al., 2019).

CS projects usually produce raw and complex datasets, which can be tricky in terms of analysis and interpretation (Bonney et al., 2009; Shirk and Bonney, 2015). Careful planning and intentional project design may provide more clarity to the data, however, at times, CS data does call for sophisticated analytic techniques to help assess and explain the complexities of multiple observers, data on efforts, and sometimes opportunistic observations (Shirk and Bonney, 2015). This underlines the importance of having an information scientist as part of the project development team or having those skills accounted for by member(s) of the project development team. Fortunately, the signal-to-noise ratio is usually favourable in CS projects, meaning strong patterns emerge which are easy to interpret (Bonney et al., 2009).

Professional and citizen science monitoring are not mutually exclusive (Pocock et al., 2014). In fact, CS data is considered to be particularly useful when paired with other datasets (Shirk and Bonney, 2015; Pocock et al., 2014; Starkey et al., 2017). This will call for the integration and assimilation of data that is produced in different ways (Shirk and Bonney, 2015), which is possible using modern analytical techniques such as hierarchical modelling (Pocock et al., 2014) or through applying data quality checks before using CS data in further steps, e.g., modelling processes (Starkey et al., 2017). Generally, this means that large-scale CS data could be paired with small-scale studies to strengthen the inferences. In addition to pairing with existing data, if there are general phenomena that are observed in the CS data, then smaller, more focused studies can be identified and pursued (Bonney et al., 2009).

Depending on the CS project, participants may also be involved in the data analysis process, e.g., in community-based monitoring projects (Shirk and Bonney, 2015). This tends to require structures and processes designed to be inclusive, effective, and efficient (Shirk and Bonney, 2015).

4.6.2 Share data and report results

There are several types of outputs associated with CS projects, which include scientific outputs, policy briefs, and reports designed for the general public. It is important to share data and updates throughout the project, with a particular emphasis on sharing at the conclusion of the project when there is data that has been analysed (de Vries et al., 2019). Participants will tend to be most interested in seeing how they have contributed to the results and assisted the overall project (Tweddle et al., 2012). It is beneficial to spend some time considering what will be the most rewarding and informative way of presenting the result to participants (Tweddle et al., 2012). It might be worth gathering this information from the participants themselves through some earlier steps and questionnaires. The extent to which participants are already engaged with the project plays a role here. As de Vries et al. (2019) point out, in collaborative or co-created projects participants may well be involved in the data analysis and thus informed about the results, so the dissemination of results is most relevant in contributory projects.

Alongside the participants, results may need to be reported and presented to other actors, including data users, funders, or the press (Tweddle et al., 2012). Research conducted by de Vries et al (2017) found mixed reaction from the participants regarding whether or not data should be shared with the public, meaning this may be something to discuss in the project development stage. If information is shared, there is likely differences in how it is relayed, depending on the level of detail and the type of data visualisation for different groups (Tweddle et al., 2012). Scientists and policymakers will tend to be interested in both the broader meaning of the results and how it fits into the wider picture and the details of the results. Media and press will want to hear key insights that explain briefly what happened, what the purpose was, and why the results are so interesting (Tweddle et al., 2012). The exact framing of the story will depend on the scope of the news outlet, i.e., regional press might be most interesting local stories (Tweddle et al., 2012). Another outlet for CS results is in the development of online decision-support tools for policymakers and land managers, e.g., the Avian Knowledge Network (Bonney et al., 2009). The potential for CS to be used to effect policy (and other) and changes is described in *4.6.3 Take action in response to data*.

Despite hesitation from some scientists and a lag regarding publishing CS studies in scientific journals (Schröter et al., 2017), results from CS projects have been used in scientific journals, such as the results from the CLO (Bonney et al., 2009). That results from CLO CS projects have been published in a range of scientific journals may not represent the general case, as CLO have been active in the CS field for several decades and are an organisation that can combine many skillsets into a given CS team. However, de Vries et al. (2017) identify three forms of scientific output present in the ECSA principles. These are: (1) the data gathered during the course of the project which should be shared and accessible, (2) the project findings, which is what has been done with the data collected, and (3) the recognition of project participants in publications. There are numerous instances where the latter of these has not been done. Kullenberg and Kasperowski (2016) report on a study where contribution of data by citizen scientists amount to almost 50% in the studies but proper credit was in most cases absent. Communication of the significance of their contributions is something that many participants have identified as an important factor, which aligns with their motivation to contribution to scientific endeavours (de Vries et al., 2019). The motivation of being able to learn new things is also served by sharing data sets (de Vries et al., 2019), alongside data visualisation and analysis tools (Bonney et al., 2009). Indeed, opportunities for participants to manipulate and study project data could act as one of the most educational aspects of CS (Bonney et al., 2009). **Sharing the project data – where non-sensitive – will maximise the value of data as others can use them. This will require returning to the intellectual property rights and data protection requirements that were assessed earlier in the project.**

Projects may also publish results in technical reports with a particular target audience, i.e., public, and private landowners (Bonney et al., 2009). Results may also be shared through mainstream mediums, such as magazines, newspapers, or newsletters. CLO publish their results through a quarterly newsletter, called BirdScope (Bonney et al., 2009). This offers materials for general interest and demonstrates what CS projects and citizen scientists are contributing. Sharing information in these formats – particularly mediums where sign-up is not necessary – may also contribute towards citizen scientists being party to the results and project progress without needing to sign-up.

4.6.3 Take action in response to data

There is growing interest in CS from both governments and research funders, which is often driven by a desire to create positive environmental impact (van Noordwijk et al., 2021). Particularly where projects are initiated by organisations, a likely desired outcome is for the data to have results beyond answering a scientific question (Shirk and Bonney, 2015). For community-initiated projects this is likely similarly a priority, whereas it may be less the case for scientist-initiated projects (at least in the short-term). However, there tends to be a gap between the expected and released impact (van Noordwijk et al., 2021). In some case this is down to delays due to “institutionalised data pipelines”

(Shirk and Bonney, 2015, p.12). It is important that this lag between completing the project and achieving policy results, if that is the aim, is acknowledge at the start of the project to avoid any false expectations on behalf of both the participants and organising team. Managing expectations is an action that can be taken in the short term. In the longer term, there is a need to understand pathways to impact and how they may be realised (van Noordwijk et al., 2021).

Van Noordwijk et al. (2021) identified six key pathways through which CS can create positive environmental change:

I. **Environmental management:** place-based and large-scale projects can contribute data to inform environmental decisions providing the data is high quality and repeated over time. This tends to require standardised, replicable data collection.

II. **Evidence for policy**: CS can deliver evidence that informs new policy as well as evaluating policy effectiveness and informing policy implementation. This pathway tends to be better served by scientist endorsement and projects with high scientific standards.

III. **Behaviour change:** participants in CS projects experience first-hand how issues may be affecting the environment, which can act as motivation and inspiration for changes in behaviour. This is especially likely where the project has a clear call-to-action.

IV. **Social network championing:** Influencing and awareness raising through digital and traditional media can influence behaviour. This is most successful where projects can tap into existing networks of engaged people.

V. **Political advocacy:** project design and framing can motivate participants to get involved in advocacy and shape political outcomes. The data needs to be credible; the project needs to be appealing and personally relevant, and mechanisms must be in place for advocates to be heard.

VI. **Community action**: in local projects people may take collective action to address environmental issues. For this community goals and project goals should be aligned, communities need to have a key role as well as multiple forms of knowledge (e.g., traditional ecological knowledge (TEK)), and results need to be widely shared.

Box 4.11 Implementation for wetlands

As has been repeatedly discussed in this paper, wetlands are in dire states across the world, with loss and damage occurring over the centuries and escalating over recent decades. Thus, there is a huge amount of action that can be taken for wetlands on the back of CS projects. A schema for what forms of action could be taken, in line with the pathways identified by van Noordwijk et al. (2021) is given in Table 5. Designed to provide a brief insight into what actions for change could look like rather than give a comprehensive account, only one action is given per pathway.

Table 5: Examples of what forms of action could be taken, categorised under the groupings provided by van Noordwijk et al. (2021).

Pathway	Possible actions
Environmental management	Long-term, large-scale research into wetland flux dynamics can be used to manage rewetting processes in ways that reduce GHG emissions as much as possible.
Evidence for policy	Research into flooding and the mechanisms behind it can be used to examine and design water management strategies.
Behaviour change	Projects that have a clear understanding and description of how wetland use by people may lead to degrading impacts can lead to more conscious use of the ecosystem (i.e., avoiding trampling).
Social network championing	Traditional and digital media can be customised and targeted to appeal to audiences with adjacent interests to wetland protection. This includes birdwatchers, hikers, and photographers. The intention would be to widen the pool of engagement advocates for wetlands by utilising other existing interests.
Political advocacy	On the basis of research (i.e., conducting biodiversity analyses), proposed housing developments could be contested. People can be engaged on a local level to wish to preserve the current biodiversity situation and not allow urban development projects to continue through political pressure and advocacy.
Community action	Communities can take collective action to ensure that areas surrounding wetlands that have been converted to farmland don't clear-cut or mow grasses during breeding season.

4.6.4 Evaluation

Evaluating project outputs and outcomes for CS is a key priority for practitioners but is often listed as one of the major challenges (Phillips et al. 2014). It is listed here as the penultimate step in this framework; however, it is really the culmination of steps that are put in motion in the project design stage, through the setting of clear goals (Shirk and Bonney, 2015) and ongoing evaluation mechanisms (Tweddle et al., 2012; Phillips et al., 2014). Shirk and Bonney (2015) raise the option of framing the process of project design and redesign as 'adaptive management', which brings in a cyclic approach designed to facilitate continuous learning, improvement, and adaptation. This approach ensures that the effectiveness of the project activities improve over time and that activities may respond to changing needs and conditions (Shirk and Bonney, 2015). In this way, the final evaluation that occurs at the conclusion of a project, is a summation of ongoing evaluation that has occurred throughout.

The final evaluation is important as it offers the chance to assess and ensure that the initial objectives have been met, be those scientific or educational objectives (Bonney et al., 2009) and to track the ongoing evaluations and how the various adaptations worked out. The results of evaluation can be used as examples for future projects or can demonstrate how projects may be improved (Bonney et al., 2009; Tweddle et al., 2012). Philipps et al. (2014) found that much evaluation thus far in CS projects has been neglected or not given rigorous attention. Methods of measurement may include surveys (both pre and post project) for participants, focus groups or interviews (Bonney et al., 2009). Other forms of evaluation include (from Tweddle et al., 2012):

I. **Baseline evaluation,** where you set a baseline of e.g., scientific understanding or people's attitudes and measure the change over time;
II. **Formative evaluation**, where you assess the effectiveness of project delivery and improve the project using the outcomes as the project is still underway;
III. **Summative evaluation**, which occurs at the end of the project or during natural breaks within the project (e.g., during the winter for projects occurring in summer) with a focus on the effects and outcomes of the project in relation to the aims set at the beginning.

Possible measures of scientific contribution are (from Bonney et al., 2009):

I. Number of papers published in peer-reviews journals
II. Number of citations of results
III. Number and size of grants awarded for CS research
IV. Size and quality of CS database

Bonney et al. (2009) report that public scientific literacy is a more challenging measurement to evaluate. They list the following as possible measures:

I. Duration of involvement of project participants
II. Increased participant interest in science as a career
III. Number of visits to project websites
IV. Improved participant understanding of scientific processes

Quite a few of the qualitative methods of evaluation (i.e., surveys, focus groups, in-depth interviews) require knowledge of research methodologies (Bonney et al., 2009). This emphasises the need for this type of skillset in the organising team, or the need for external evaluation. Evaluations can be carried out by an internal or external evaluator, or a combination of both (Phillips et al., 2014). Indeed, there are many types of evaluation, including front-end evaluation, formative evaluation, and summative evaluation (see Phillips et al., 2014 for a discussion of the specifics of these evaluation types). In this step, the evaluation procedures laid out earlier in the framework will be carried out with the results being published as appropriate (see Phillips et al., 2014 for a discussion on the ethics of evaluation).

4.6.5 Acknowledgement

Projects should acknowledge and celebrate the contribution of participants (Shirk and Bonney, 2015). In structured projects, this may be in the form of awards, ceremonies, or other recognition events (Shirk and Bonney, 2015; Tweddle et al., 2012) or formats, i.e., acknowledgment sections of reports or scientific outputs or being listed as a co-author (de Vries et al., 2019). In opportunistic projects, this could be through statements on the website or social media and anonymous, generalised acknowledgements in reports or other outputs.

Often insufficient credit is given to participants (Schröter et al., 2017). In order to emphasise the need for acknowledgement, this framework has a specific step devoted to this, however, the contribution of citizen scientists may be acknowledged throughout the duration of project as well as at the end. Acknowledging the contribution of citizen scientists places participants as collaborators rather than as means to an end (de Vries et al., 2019). Ultimately the form of acknowledgement varies according to how involved participants are and whether they are taking part anonymously or otherwise, amongst other factors. The recommendation is to be clear from the outset what kind of acknowledgement is proposed and listen to feedback from participants regarding any changes they want to see made to the proposal.

Box 4.12 Implementation for wetlands

Analogous to other CS projects, acknowledgements for involvement in wetland CS projects could be given at the beginning of scientific papers with participants either listed as co-authors or with a word of acknowledgement at the beginning of the paper. Thanks to various wetland organisation, who may also recognise the importance of CS (e.g., Ramsar), there is the possibility of hosting awards ceremonies, making social media posts, or otherwise acknowledgement participants in partnership with these organisations. There could even be celebrations for citizen scientist of the year, or other related content and events aimed at recognising the work of participants whilst also appealing to a wider audience, allowing them to see both the project and the involvement of participants.

5 Conclusion

This report set out to assess the state of the field of CS, taking an encompassing view that takes stock of definition, impact & potential, reception & challenges, status in the EU and status in wetland research and conservation, and project design and implementation. The literature review that considered each of these aspects demonstrates that CS is still an emerging field yet has already made a significant impact. This is particularly the case when an expansive view is taken, one that includes projects and work that has been done outside of the term ‘citizen science’. There remain challenges, especially regarding professional scientist involvement, which is largely considered a prerequisite to a successful citizen science project, and potential scepticism from these actors. Additional challenges involve building new practices that serve a CS approach, which requires a strong focus on communication between the multiple actors that are involved in citizen science projects. This report also presents an insight into how CS is being used within the EU and for wetland research and conservation, which contributes to the CS field as it provides an overview which has not been thoroughly given thus far. Finally, the report describes the importance of project design and implementation, which is considered a crucial component that must be given breadth and time in order to ensure the success of the project.

Based on the extensive thematic literature review and existing literature, a framework or guideline was created as part of the present report that considers how citizen science can be used for wetlands to optimal effect. This framework is very detailed, taking a macro approach to what components may be included in a framework. As discussed throughout the framework description, it should be viewed in a modular manner, with different elements being most important for particular CS projects, certain steps not needing to be taken, or for circling back to previous steps. Ultimately, the framework sets out that the most important consideration, no matter what particular pathway a CS project takes, is to give enough time and detailed thought to each of the possible steps and what fits best in a certain circumstance. By doing so, it is certainly possible to create a framework that balances and achieves all three of the aspects listed in the research question: accessibility for non-scientists, being scientifically robust, and serving as an outreach and awareness tool.

Wetlands are crucial ecosystems, which offer ecosystem services across all the major groupings: cultural, provisioning, regulating, and supporting. Despite this, they are in rather dire situations across the world, with many wetlands being lost or degraded in Europe. Additionally, there is a lack of information about particular aspects of wetlands, including their extent across Europe and worldwide, what the trends in terms of degradation and restoration are, and how climate change may impact them going forwards. To add to this situation, there is a deficiency in the knowledge that does exist on the importance and research of wetlands reaching the general public. CS, with its ability to serve multiple purposes, is proposed as an ideal way of alleviating this lack of knowledge and research, the need for more public awareness, and the conditions for extensive wetland restoration.

The framework set forth in this report acts as one step towards building a practical, useful, and valuable framework for use in wetlands. This report does not include a practical component wherein the framework is tested in the field, which acts then as one of the next steps in this process. Building case studies into the framework will strengthen it and demonstrate the importance of generalised guidelines whilst tailoring the specifics to the local conditions and circumstances. Alongside this, there is a continued need for further research on the social aspect of CS, including whether and in which ways it engenders civic empowerment and what power dynamics are at play when professional and citizen scientists work together and how to manage these within CS projects, with an eye on discovering new relationships between society and scientists outside of CS alone.

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