Exploring inclusivity in citizen science: an assessment and recommendations

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ABSTRACT

Adopted by 193 countries, the United Nations 2030 Agenda for Sustainable Development provides a globally agreed collective roadmap for achieving peace and prosperity sustainably and is committed to equality and inclusion. Citizen science has emerged in recent years as an important field of scientific research that can support the Sustainable Development Goals (SDGs), and also democratise science by including diverse groups of participants in scientific research. Public involvement can also encourage engagement and education around sustainability while raising awareness about the SDGs. Although citizen science projects often understand inclusivity in terms of diversity, recent research suggests a shift towards more authentic involvement which actively involves communities in project design and decision-making about sustainability. Acknowledging this shift, a key consideration in citizen science is understanding how varying conceptualisations of inclusivity influence the design and outcomes of projects. By drawing insights from existing literature and examining various case studies, this research analysed, scored, and explored, how four different concepts of inclusivity including demographic diversity, (II) educational diversity, (III) accessibility and (IV) participation, influence the design and results of citizen science projects. Additionally, this study provides fifteen recommendations for designing inclusive citizen science projects informed by these conceptualisations. This study is positioned within the broader framework of the United Nations 2030 Agenda for Sustainable Development which highlights the transformative impact of equality and inclusion, and the aim of the research is to support an inclusive approach to citizen science.

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1.0 Introduction

1.1 Background and context

Established in 2015, the United Nations (UN) 2030 Agenda for Sustainable Development provides a comprehensive framework for achieving sustainable development globally. The agenda is committed to "*leaving no one behind*" to ensure that progress towards development is inclusive and that the benefits of development reach all groups of society. Acknowledging the transformative impact of equality and inclusion, António Guterres, Secretary-General of the United Nations, has stressed that "*inclusion, empowerment, and equality must be at the heart of our efforts for development to be sustainable*" (United Nations, 2019).

This commitment to inclusiveness is particularly relevant in the field of citizen science. By designing projects that are inclusive and accessible to all, regardless of socioeconomic status, education level, or geographic location, citizen science can ensure that everyone has the opportunity to contribute to, and benefit from, scientific research. Furthermore, given that the UN Agenda requires transformative thinking and innovative approaches to address global challenges, citizen science has the potential to encourage new ways of finding sustainable solutions to longstanding problems.

Nevertheless, although the 2030 Agenda provides a collective roadmap for sustainably achieving peace and prosperity, according to the 2023 Sustainable Development Goals Report, the SDGs are not on track with more than 50 percent confirmed as "*weak or insufficient*" and 30 percent halted or in reverse, including key targets on poverty, hunger, and climate. Despite gaps, insufficiencies, and failures, the report emphasises the enormous potential to realise the goals through political will and more effective use of existing knowledge and resources (Sustainable Development Goals Report, 2023).

Within this framework, citizen science can support progress towards, and monitoring of, the SDGs through 1) the provision, availability, and exchange of high-quality, up-to-date data to track progress, and 2) increasing public engagement and interest in the SDGs to facilitate broader societal changes (West & Pateman, 2017). Accurate monitoring and reporting of environmental data is important in terms of achieving the SDG targets, however, the use of traditional data sources such as national statistical offices (NSOs) can lead to irregular, out-of-date, or inaccurate data due to regional limitations and variations (Ballerini & Bergh, 2021, Fraisl & See, 2020). Non-traditional data sources through citizen science initiatives can provide a cost-effective means to not only increase the quantity and geographic spread of data collection, but also improve granularity and timeliness (Proden *et al.*, 2022; Fritz *et al*., 2019).

Public involvement in scientific research also has the potential to encourage public engagement and education around sustainability while raising awareness about the SDGs as well as promoting action towards achieving them. According to Fraisl *et al*. (2020), citizen science is already making a significant contribution in monitoring five of the SDG indicators and suggest there is potential to contribute to a further seventy-six indicators, particularly in relation to SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 15 (Life on Land).

1.2 Introduction to citizen science

In recent decades, the realm of scientific research has expanded far beyond the traditional boundaries of academia, with public participation in scientific research gaining significant momentum. Often referred to as "*citizen science*", the term is associated with multiple everchanging definitions (Eitzel *et al*., 2017). According to Haklay *et al*. (2021), it is derived from two epistemological stances which include (I) an original conception which views citizens as stakeholders in research outcomes, and (II) a perspective which involves volunteer contributions coordinated by professional scientists. More recently, it refers to different levels of participation in knowledge creation and overlaps with participatory action research and Citizen Generated Data (CGD). Indeed, according to Cooper *et al*. (2021), it has assumed a "*big tent*" definition which encompasses not only data collection but public participation in research and education across a diverse range of projects with goals such as scientific advancement, engagement, education, policy, and empowerment.

While it has been argued that universal agreement on the definition of "*citizen science*" is necessary for acceptance in the field of science (Heigl *et al*., 2017), universal consensus has the potential to exclude citizen participation in research processes that do not fall within the boundaries of an agreed definition and therefore a binding definition is not advisable if citizen science is to remain genuinely inclusive (Auerbach *et al*. 2017). However, understanding the differences between these definitions is important for practitioners and policymakers to support citizen science to its fullest (Haklay *et al*., 2021). This is particularly relevant in terms of the 2030 Agenda, as citizen science has the potential to not only function as an effective tool for monitoring ecosystems, but also plays an important role in achieving the SDGs and facilitating the societal transformations that are needed to meet these targets.

1.3 Aspects of inclusivity in citizen science

Within the context of citizen science, the concept of inclusiveness is as varied and multifaceted as the definitions of citizen science itself. For Strähle *et al*. (2022), inclusion is fundamental to the concept of citizen science and, in the simplest of terms, means that everyone who wants to participate has an equal chance to do so. However, inclusiveness also incorporates a broader range of meanings and can refer to the participation of diverse demographic groups, and individuals from various educational backgrounds, the accessibility of a project in terms of factors such as language, technology, cost and physical access, the involvement of non-professional scientists in research design and execution, and even the integration of local and indigenous knowledge into scientific projects. These broader interpretations of inclusiveness align with the "*big tent*" definition of citizen science noted by Cooper *et al*. (2021), which aims to democratise science by making it accessible for everyone.

Achieving inclusiveness presents challenges as it requires overcoming existing barriers in society that limit participation based on factors such as socioeconomic status, education and geographic location. Despite the lack of agreement about what inclusivity is, Cooper *et al*. (2021) discuss the idea of "*centering around the margins*" to ensure genuine inclusivity in citizen science and argue that a project will be universally accessible if it is accessible to marginalised communities.

However, the inclusiveness or exclusiveness of an initiative cannot be based solely on the observable diversity or homogeneity of a group (Georgi, 2014). The appearance of diversity alone doesn't guarantee inclusiveness, nor does homogeneity necessarily indicate exclusiveness. Understanding these nuances and addressing barriers is crucial for practitioners and policymakers to create genuinely inclusive citizen science.

Against this backdrop, this research presents a conceptual framework to illustrate how four interrelated dimensions of inclusivity in citizen science affect project design and outcomes and collectively shape the inclusivity of a citizen science project which are: (I) the demographic diversity of participants, (II) the accessibility of the project in terms of removing practical barriers to participation, (III) the educational diversity of participants, and (IV) the level of meaningful involvement of participants throughout the scientific research process.

1.3.1 Introduction to Demography

While citizen science has traditionally involved non-professionals in scientific research, there has been a significant shift toward inclusive participation (Paleco *et al*., 2021) and examining inclusiveness across various axes including age, gender and socio-economic background (Pateman *et al*., 2021). Indeed, the goal of diversity in citizen science is to engage a broad spectrum of participants and democratise science by involving diverse groups (Hecker *et al*., 2018).

However, despite these developments. many citizen science projects still engage "empowered" participants particularly in the Global North (Lewenstein, 2022; Pateman & West, 2023) which represents a considerable challenge to diversity. Waugh *et al*. (2023) argue that this underrepresentation is often due to social stratification and socio-economic barriers which are compounded by a lack of prior experience in citizen science within marginalised communities. Overcoming these barriers is important, as research indicates that increasing diversity in citizen science benefits both the scientific community and the participants involved (Bonney *et al*., 2016, Paleco *et al*., 2021).

Although diversity is crucial to broaden the range of perspectives in scientific research, inclusiveness in terms of level of involvement can be more transformative as it also ensures that participants are meaningfully engaged and can contribute in ways that reflect their interests and skills. Waugh *et al*. (2023) argue not only for diversity, but for support of community-based projects that are designed by, and for, marginalised groups to enhance inclusiveness through levels of involvement and create genuine and effective participation. See Table 1 (page 35) which illustrates more fully how inclusivity in terms of accessibility in citizen science affects and can be included, assessed and monitored in project design and outcomes.

1.3.2 Introduction to Education

Accommodating educational diversity and varying levels of scientific literacy is an important factor that is often not considered within ideas of inclusivity in citizen science initiatives. With scientific literacy defined as the ability to "*engage with science-related issues, and with the ideas of science, as a reflective citizen*" and explain phenomena scientifically, evaluate and design scientific enquiry and interpret data and evidence using scientific methods (OECD PISA, 2015), it is clear that scientific literacy levels significantly impact how many individuals can engage with, and contribute to, scientific research in the field of citizen science.

Given that studies indicate that educational background plays a significant role with some segments of the population more inclined to take part in citizen science as a result of their level of education, it is important that uniqueness and diversity is not only respected, but also represented (Paleco *et al*., 2021). Furthermore, while citizen science seeks to engage individuals to contribute to research and arguably attracts certain societal groups, this scientific research is based on existing scientific knowledge systems, however, Indigenous and Local Knowledge (ILK), as distinct and complementary knowledge systems (Tengö et al., 2021) have the potential to make valuable contributions to current knowledge in sustainable ways. Citizen science not only requires diversity in levels of education within existing frameworks, but also diversity in knowledge systems, to ensure a more inclusive approach in methods of scientific inquiry. See Table 2 (page 36) which illustrates more fully how inclusivity in terms of accessibility in citizen science affects project design and outcomes.

1.3.3 Introduction to Accessibility

While the concept of accessibility is often associated with disabilities, the International Organisation for Standardisation (ISO) definition refers to it as the "*extent to which products, systems, services, environments, and facilities can be used by people from a population with the widest range of user needs, characteristics, and capabilities to achieve identified goals in identified contexts of use*" (ISO, 2018). This definition aligns closely with universal design principles that support the creation of products, systems, or services that consider the widest possible range of users and utilities from initial conception, rather than retrofitting features, and incorporates multiple spaces from the concrete and physical to the digital, including access to information, data and even project results (Heinisch, 2021). Therefore, ensuring that citizen science initiatives are inclusive requires addressing technical, psychological and sociological factors (Unterfrauner *et al*., 2021).

There are several strategies for consideration in project design that can improve the participation of people with specific accessibility needs including: (I) inclusive research design from initial conception to final deliverable and active involvement in the research design process, (II) a co-creation process where researchers collaborate with wheelchair users, (III) identifying and addressing barriers to participation that may be present in traditional research practices, (IV) capacity building through the recognition of expertise, and (V) adherence to the principles of citizen science, which emphasise that citizen science should not only be the result of decisions made by professional scientists, but can also be initiated by citizens themselves (Krüger et al., 2023).

The 10 Principles of Citizen Science (ECSA, 2015) outline key principles for good practice in citizen science while acknowledging the flexibility of citizen science as a concept which can be tailored to meet the requirements of diverse situations. Although these influential guidelines encourage key aspects of inclusivity including that citizens "*may act as contributors, collaborators, or as project leaders*" (Principle 1), "*may participate in multiple stages of the scientific process*" (Principle 4), and that results are published in an "*open access format*" (Principle 7), it does not include a requirement for universal design principles to ensure broader accessibility for individuals with diverse needs and abilities. In the European context, citizen science project designers can refer to the European Accessibility Act (EAA) which aims to simplify accessibility rules across the European Union and ensure more accessible products and services are available for people with disabilities. See Table 3 (page 37) which illustrates more fully how inclusivity in terms of accessibility in citizen science affects project design and outcomes.

1.3.4 Introduction to Participation

Although citizen science historically involved citizens in a contributory capacity in researcher-led initiatives, a move to more democratic processes with a focus on citizen empowerment has been seen in recent years to support a transition to sustainability (Sauermann *et al*., 2020). Science is increasingly adopting participatory methods to generate knowledge, recognising that our complex social and environmental systems are better understood through diverse perspectives and forms of knowledge (Alvarado et al., 2020; Tengö et al., 2014). In line with this growing trend, Shirk *et al*. (2012) categorised public participation in scientific research (PPSR) according to different degrees of public participation (see Table 5) and argued that both the extent and depth of participation - the degree to which individuals are involved - and the quality of participation - how well a project's goals align with public needs and interests - heavily influence project outcomes. Their analysis suggests that design choices concerning the quality of participation and whose interests are served have a greater impact on outcomes than the degree of involvement alone. Understanding the diverse purposes and methods of public participation is instrumental to designing more meaningful and effective ways for the public to be involved in knowledge generation (Wehn *et al*., 2015).

In this context, drawing on participatory community engagement approaches to climate change assessment and public health, Pandya *et al*. (2012) developed a framework to guide the design of more inclusive citizen science projects. This framework emphasises the importance of involving the public in defining research questions that address community goals and interests as well as scientific goals. See Table 4 (page 38) which illustrates more fully how inclusivity in terms of participation in citizen science affects project design and outcomes.

1.4 Aims and objectives

Despite the achievements and the potential of citizen science, many projects struggle with inclusivity and barriers to participation and reflect similar exclusionary processes which exist in the field of science and more broadly in society (Varga *et al.*, 2023). Although citizens science projects often strive for inclusivity and seek to engage diverse participants, recent research suggests a shift towards deeper, authentic involvement which actively involve communities in project design and decision-making about sustainability. Acknowledging this shift, a key consideration in citizen science, therefore, is understanding how varying conceptualisations of inclusivity influence the design of citizen science projects.

This research explores how these different concepts of inclusivity influence the design and outcomes of citizen science projects. By drawing insights from existing literature and examining various case studies, the aim is to identify best practices and provide recommendations for enhancing inclusivity in citizen science. This study is positioned within the broader framework of the United Nations 2030 Agenda for Sustainable Development which highlights the transformative impact of equality and inclusion and aims to support an inclusive approach to citizen science projects.

Objectives

- To analyse how different concepts of inclusivity are operationalised in selected case studies on citizen science projects.
- To evaluate the impact of these concepts on project design, and outcomes.
- To provide recommendations for designing inclusive citizen science projects in the context of the SDGs.

2.0 Methods

This study involves a qualitative analysis to examine how conceptualisations of inclusivity impact program design and outcomes in citizen science projects and includes the following components: (I) a literature review, (II) a conceptual framework, and (III) the application of a thematic framework to examine selected case studies.

2.1 Literature review

The literature review incorporates journal articles, books, and reports sourced from databases including Google Scholar, Semantic Scholar, and Google Search using terms based on the research topic. The search terms include "citizen science," "inclusivity," "inclusiveness," "public participation," "biodiversity" "environmental monitoring". "diversity," "education," "accessibility". Academic materials were selected on the basis of their relevance to the search topics and incorporate key themes, models and frameworks in citizen science.

2.2 Conceptual framework

A conceptual framework explains, either graphically or in narrative form, the key factors, variables, or constructs and the presumed interrelationships among them and can be simple or elaborate, commonsensical or theory driven, descriptive or causal (Miles & Huberman, 1994). This research presents a conceptual framework to illustrate how four interrelated dimensions of inclusivity in citizen science affect project design and outcomes and collectively shape the inclusivity of a citizen science project which are: (I) the demographic diversity of participants, (II) the educational diversity of participants, (III) the accessibility of the project in terms of practical barriers, and (IV) the level of involvement of participants throughout the scientific research process.

2.3 Thematic framework

The thematic framework (see Table 6) is used to examine how varying conceptualisations of inclusivity affect program design and outcomes in citizen science projects. The framework will guide the review of the case studies and includes the following dimensions: i) demography, ii) education, iii) accessibility, and iv) participation.

2.4 Selection of case studies

Five case studies were selected to examine the relationship between inclusivity variables and project outcomes and to provide evidence and practical insights into how concepts of inclusivity impact citizen science projects. The selection was based on the following criteria: (I) relevance to the four concepts of inclusivity in citizen science as outlined in the framework, (II) diversity in type, scale, and geographic location, (III) availability of information on project design including recruitment and outreach strategies, participation methods, training and support programs, and communication and feedback mechanisms, and (IV) clear outcomes in terms of scientific contributions, community impacts, and participant benefits.

2.4.1 Irish Butterfly Monitoring Scheme

As Ireland's longest running citizen science insect monitoring initiative, the Irish Butterfly Monitoring Scheme tracks the status of butterfly species via a series of networks where butterfly numbers and flight periods (phenology) are recorded by volunteers. The aim of the project is to create a multi-species population index as a measure of the health of the butterfly population and to contribute to the European Butterfly Monitoring Scheme. This evaluation is important as butterfly population health is also a good indicator of the health of the environment and can provide insights into how insect populations are impacted by land-use and climate change. The scheme uses statistical analysis of the data to ensure it meets the threshold for detecting trends and produces an annual report of the results which is made publicly available on the

Biodiversity Ireland website. This project contributes to SDG 15 (Life on Land) by monitoring butterfly populations as indicators of ecosystem health, SDG 13 (Climate Action) by providing insights into how climate change affects insect populations, and SDG 17 (Partnerships for the Goals) through collaboration with the European Butterfly Monitoring Scheme.

2.4.2 Malta Pollinator Monitoring Scheme

Launched by the Environment and Resources Authority (ERA) in Malta in 2023, after a public consultation process on the National Strategy and Action Plan for Pollinators to 2034, the Malta Pollinator Monitoring Scheme (MPOMS) is a citizen science project designed to gather information on pollinators such as bees, butterflies, moths, birds and lizards through field surveys conducted by participants (Environment and Resources Authority, 2024). Pollinators are essential for maintaining ecosystem health and biodiversity as they play a key role in pollinating crops and wildflowers which provide habitat and food for a wide variety of species including insects, birds and mammals. The main goal of the initiative is to improve knowledge about pollinator populations and develop effective ways to protect, manage and conserve pollinators. The project supports the EU Pollinators Initiative which addresses the decline of pollinators in the EU and contributes to global conservation efforts (European Commission, 2023). The project contributes to SDG 15 (Life on Land) by enhancing the understanding and conservation of pollinators for ecosystem health and biodiversity, SDG 13 (Climate Action) by supporting conservation efforts that can influence climate resilience, and SDG 17 (Partnerships for the Goals) by aligning with the EU Pollinators Initiative.

2.4.3 INCREASE Citizen Science Experiment

The INCREASE project aims to increase agricultural biodiversity in Europe by adopting novel approaches to the conservation and management of food legumes such as chickpea, common bean, lentil, and lupin. Through the INCREASE Citizen Science Experiment, the project aims to test an innovative approach to seed conservation, multiplication and sharing in order to conserve agrobiodiversity. (INCREASE, 2023). This project has successfully completed extensive work in genetic diversity and adaptation within common bean cultivars and aims to produce phenotypic data for over 1,000 bean plant genetic resources. This project contributes to SDG 2 (Zero Hunger) by enhancing agricultural biodiversity and promoting sustainable food systems, SDG 15 (Life on Land) by conserving agrobiodiversity and managing genetic resources, and SDG 17 (Partnerships for the Goals).

2.4.4 The Distributed Network for Odour Sensing Empowerment and Sustainability (D-NOSES)

As a citizen science project designed to address urban noise and odour pollution through citizen engagement and data collection, D-NOSES (Dealing with Noise and Smell in European Cities) aims to create detailed pollution maps across Europe to inform urban planning and policy decisions and raise public awareness. Increased and ongoing exposure to odour pollution is often an indicator of broader environmental issues and has a notable negative impact on communities in terms of health and quality of life (D-NOSES Policy Brief, 2023). The project seeks to address this issue through the application of a holistic approach to researching and developing regulatory frameworks that will build the foundation for odour pollution control and empower the public to become change agents in their communities through citizen science. The project contributes to SDG 11 (Sustainable Cities and Communities) by addressing urban pollution and informing urban planning, SDG 3 (Good Health and

Well-being) by mitigating health impacts from pollution, SDG 16 (Peace, Justice, and Strong Institutions) by promoting citizen engagement and transparent governance, and SDG 13 (Climate Action) by addressing environmental issues related to urban pollution.

2.4.5 Sea Plastics Consequences Study (SeaPaCS)

With the goal of addressing the issue of marine plastic pollution through a combination of scientific research and community-based approaches, the SeaPaCS (Sea Plastic Consequences Study) citizen project aims to raise awareness about the impact of marine plastics in Anzio in Italy, encourage transformative action to adopt sustainable behaviour, investigate the impact of microbial communities living in the Mediterranean plastisphere and leverage local knowledge to minimise plastic marine waste. The project contributes to SDG 6 (indicator 6.3) on water-related ecosystems, SDG 14 (indicators 14.1 and 14.2) on the consequences of marine plastic pollution towards sustainable use of the ocean and addresses SDG 15 (indicator 15.8) on biodiversity loss.

3.0 Results

The case studies were assessed using the thematic framework (see Table 6) using twenty different measurable indicators which explores how varying conceptualisations of inclusivity affect program design and outcomes in citizen science projects and guides the analysis related to the four concepts of inclusivity.

The five different citizen science projects assessed were scored, (see Table 7) with each "Yes" awarded 1 point and each "No" awarded 0 points (Figure 1). All projects scored evenly on demographic distribution and received the maximum of 3 points, with the exception of the Irish Butterfly Monitoring Scheme, which did not include diversity in its project design and scored 0. All projects also scored evenly on educational diversity and were awarded 1 point, as each initiative supplied training resources that could support people from varying educational backgrounds. D-NOSES was the most accessible of the projects, receiving the maximum of 3 points as it facilitates physical access for people with disabilities, followed by all other projects with 2 points. Although each project received 1 point for contributory participation, INCREASE, D-NOSES, and SeaPaCS received an additional point for integrating local knowledge into their designs, with SeaPaCS and D-NOSES receiving the maximum of 4 points in terms of participation. Each project scored well in terms of engagement and received the maximum of 4 points, with the exception of the Irish Butterfly Monitoring Scheme, which scored 2 points. as the result of more limited engagement with partnerships and academia. All projects were also awarded a full point for training and support as well feedback mechanisms. The INCREASE project scored the highest in terms of reporting across all channels and received the maximum 3 points, compared with 2 points for all other projects.

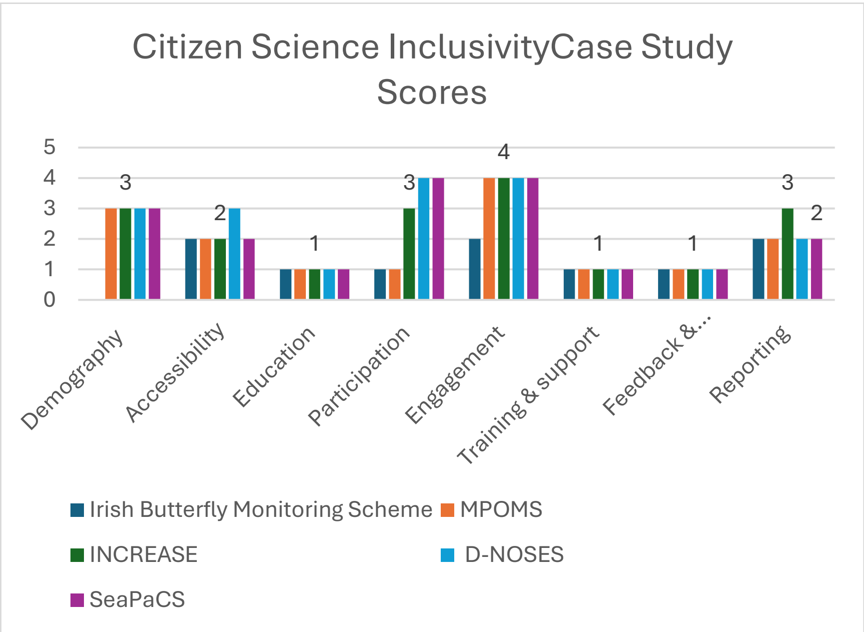

Figure 1: Citizen Science Inclusivity Scores per category

Final scores:

I. Irish Butterfly Monitoring Scheme: 10/20

II. Malta Pollinator Monitoring Scheme (MPOMS): 15/20

III. INCREASE Citizen Science Experiment: 18/20

IV. Distributed Network for Odour Sensing Empowerment and Sustainability (D-NOSES): 19/20

V. Sea Plastics Consequences Study (SeaPaCS): 18/20

The maximum score for inclusivity was 20 (Figure 2). None of the projects scored 20/20. D-NOSES scored the highest for inclusivity with 19/20 and received full points across all categories except on reporting. SeaPaCS and INCREASE scored well for inclusivity receiving 18 points each. The monitoring schemes were the least inclusive with MPOMS indicating a moderate level of inclusivity at 15 points, and the Irish Butterfly monitoring scheme receiving the lowest score of the projects with 10 points out of the maximum of 20 points.

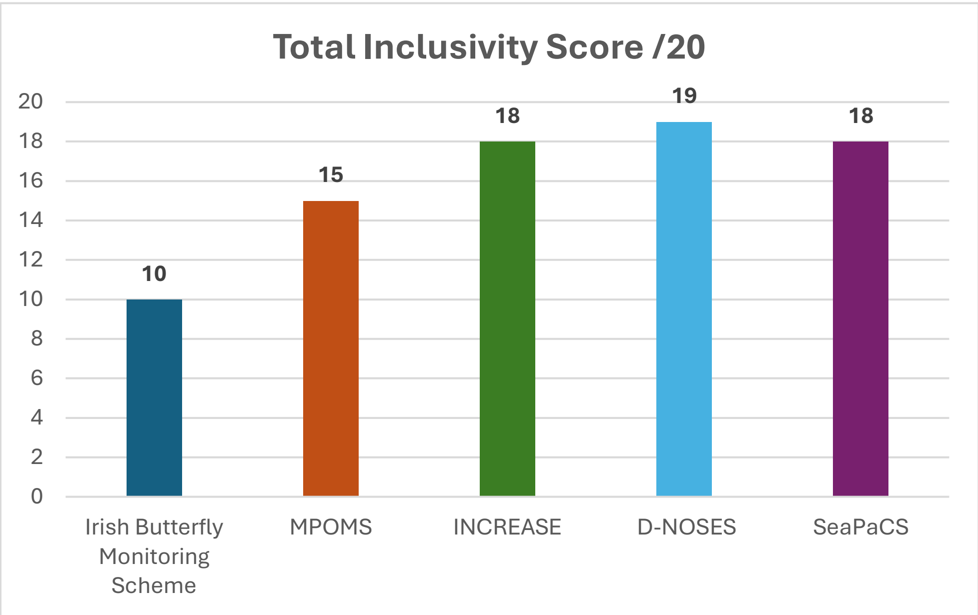

Figure 2: Total Inclusivity Score for each of the citizen science projects studied

Looking at each study individually, the following observations on the impact of inclusivity on project design were also made.

I. The Irish Butterfly Monitoring Scheme uses a contributory citizen science model, which focuses on gathering comprehensive multi-species population data to assess the health of butterfly populations. Inclusivity is not an objective of the project, and the demographic diversity of the project has not been reported and is unknown. The citizen scientist's role as a "*sensor*" is centred around data collection, which impacts the design of the project in multiple ways, including: (I) the use of general callouts through already existing networks for recruitment rather than targeted strategies to attract a diverse participant base, as the quality and quantity of data is prioritised, (II) the freedom for participants to select the routes they wish to monitor, which allows for flexibility in terms of access, however, participation is limited to individuals proficient in English and may pose a barrier to non-English speakers, (III) the scheduling of training events and the provision of online training resources and guides, however, the scheme doesn’t cater to diverse educational backgrounds or various learning needs, and (IV) the receipt of participant feedback through email which facilitates engagement and possibilities for improvement to the citizen science experience. As a result, the project outcomes include accurate and reliable data on the butterfly population and increased awareness about the importance of butterflies in the Irish ecosystem, but lacks exploration into the possible benefits of adopting a more inclusive approach in terms of the scope of the research. This approach represents a low level of inclusiveness.

II. The Malta Pollinator Monitoring Scheme (MPOMS) uses a contributory citizen science model which focuses on inclusivity in terms of demographic diversity and invites people of all ages, backgrounds, and professions to participate in the project. This emphasis on diversity shapes several aspects of the project design, which include: (I) the use of broad recruitment strategies through social channels and traditional media, as well as community events to attract a diverse participant base across age, gender, and socio-economic status, (II) the design of flexible fieldwork schedules and alternative transport options to help address accessibility challenges and accommodate varying needs, however, the nature of the research which involves remote fieldwork poses challenges which are difficult if not impossible to overcome, (III) the provision of introductory training and a digital field guidebook as well as expert guidance during field trips to support participants regardless of their prior knowledge, and (IV) incorporating regular participant feedback to refine the project based on participant input with ongoing communication through a dedicated WhatsApp group. As a result, the project outcomes include comprehensive and reliable data on pollinators while also improving participant engagement and raising a broad awareness of pollinator populations across a wide demographic spectrum, however, while participants feedback is valued, participants are not engaged in the research design. This approach represents a moderate level of inclusiveness.

III. Guided by the European Commission principles "open science, open innovation and open to the world" INCREASE employs a collaborative participatory citizen science model to engage a diverse range of community members in evaluating and conserving genetic resources and to educate the public about legume biodiversity. This approach impacts on the design which: (I) includes extensive multilingual resources and digital platforms to engage a broad demographic with 5,000 participants of different backgrounds, ages, and gender across Europe participating in the 2024 campaign, (ii) offers three levels of participation subject to an individual's level of experience and availability to facilitate numerous levels of scientific literacy. (iii) involves training and support which includes extensive multilingual guides, tutorials, and step-by-step instructions to assist participants regardless of their prior knowledge, and (iv) includes regular feedback mechanisms and communication through dedicated online channels in multiple native languages to facilitate continuous improvement informed by the participant experience. As a result, the project outcomes include the promotion of genetic diversity of legumes in Europe as well as improved data quality, increased public awareness of biodiversity, and more sustainable agricultural practices. By democratising access to seeds, INCREASE also promotes sustainability and food sovereignty by challenging the dominance of agricultural corporations. This approach represents a high-level of inclusiveness.

IV. D-NOSES aims to introduce a bottom-up approach to odour governance using citizen science and employs a collaborative and co-designed contributory model. The project views individuals as "*co-responsible*" members of society and therefore advocates for local decision-making and management processes to increase awareness of local environmental challenges, drive behavioural change, and provide opportunities to co-create local regulations as sustainable communities (D-NOSES Policy Brief, 2021). This unique approach impacts significantly on the project design in multiple ways, including: (I) the use of multilingual resources such as the D-NOSES engagement toolkit and diverse digital platforms to ensure participation from various backgrounds and regions for effective recruitment and broad outreach, (II) integrating tools like the OdourCollect app and Smell Diaries to accommodate multiple levels of expertise and varying degrees of digital access, (III) the provision of training through workshops and direct interactions with project experts as well as multilingual guides to facilitate participants from different educational and cultural backgrounds, and (IV) regular communication and opportunities for feedback through ongoing community engagement, co-creation workshops, and adaptive strategies to incorporate participant input. D-NOSES stress that that "*informed opinion and active co-operation on the part of the public are of the utmost importance*" to achieve their project goals to improve public health. As a result, the project outcomes include the generation of new data with greater access to information, increased public participation in local decision-making and advocacy actions to introduce odour pollution to policy agendas, and improved confidence in public authorities. This approach represents the highest level of inclusivity.

V. SeaPaCS understand inclusivity from the perspective of social inclusion and cultural diversity and involves the community in every phase of the project beyond data mapping, from project design to analysis, with a focus on local issues that are relevant or identified by local stakeholders. SeaPaCS actively acknowledges the importance of local knowledge and its integration into the project, and this impacts the project design in significant ways which include: (I) engaging diverse stakeholders such as local fishermen, migrants, and students through "*collaboratoriums*" to support recruitment and broaden outreach, (II) the use of methods which incorporate co-designed approaches and utilise feedback from diverse participants to help co-design and refine research tools and strategies, (III) the provision of training and support through tailored sessions and resources that support varying levels of scientific literacy and cultural backgrounds, and (IV) communication and feedback through ongoing participatory sessions that facilitate active stakeholder input and project adaptation based on feedback. This impacts on the project outcomes resulting in increased awareness about plastic pollution and related health risks and the importance of sustainable tourism, future planning for marine plastic monitoring and recycling by local communities. socially sustainable management of the marine environment and citizen empowerment through collective action. This approach represents a high-level of inclusiveness.

4.0 Discussion

While there are many interpretations of inclusivity in citizen science, the idea of engaging a diverse group of people from various socio-cultural and economic backgrounds, as well as different ages and genders, is perhaps the first step towards an inclusive practice in citizen science. Incorporating diversity is important as it has benefits for science, participants, and society. However, the lack of diversity in citizen projects is well documented and indicates that the majority of participants come from socio-economically advantaged backgrounds and are male, highly educated, and academically skilled (Cooper *et al*., 2021). Consequently, citizen science is at risk of perpetuating the disparities, prejudices, and underrepresentation that have affected the scientific community.

The problems relating to a lack of diversity in citizen science are manifold and can negatively impact the quality of data and the lives of communities. For example, homogeneity in project design can result in biases in datasets, which impact their viability and comprehensiveness (Pateman & West, 2023). Furthermore, a failure to recruit participants from diverse backgrounds can also lead to gaps in the data, particularly in relation to projects such as D-NOSES, which rely on experiential knowledge. In this context, perspectives can be excluded from research, resulting in decisions or policymaking that fail to represent the needs of these communities and further marginalise underrepresented groups, and reinforce societal inequities (Pateman *et al*., 2021; Grineski *et al*., 2022).

These challenges can be overcome at all levels of citizen science participation if diversity is incorporated into the project design. For co-designed projects such as D-NOSES and SeaPaCS, diversity is fundamental to the design as the goal is to achieve sustainable project outcomes that align with community interests and needs, which supports sustainable practices. However, contributory models, where participants act primarily as data collectors, can design projects with a focus on outreach and incorporate extensive recruitment strategies to reach a diverse participant base, such as the MPOMS project. The use of multilingual resources and online support can increase diversity in collaborative models such as the INCREASE project, which has facilitated citizen participation across Europe to ensure that demographically diverse groups and remote communities have equal opportunities to contribute to conservation.

The benefits of incorporating diversity in the project design are extensive and result in more complete and representative datasets from larger and more diverse geographic areas, with opportunities to incorporate information from underrepresented communities to generate new scientific knowledge and research questions (Pateman & West, 2023). From the point of social sustainability, the inclusion of diverse groups also enhances community representation and the relevance of findings to local communities (Dickinson *et al*., 2012), which supports sustainable practices. According to Rotman *et al*. (2012), it also increases participant engagement and learning outcomes.

Inclusivity in educational diversity where people from a wide range of educational backgrounds can participate in citizen science is another key element for consideration in terms of inclusivity. However, when diversity is considered in project design, it is often understood with regard to age, gender and socio-economic background. Furthermore, knowledge is considered within the context of conventional education, however, acknowledging and integrating traditional and indigenous knowledge in citizen science projects is also important as it provides opportunities to include perspectives which are not always represented. With 370 million Indigenous Peoples worldwide, ILK is crucial for achieving the SDGs and represents enormous untapped potential for developing solutions to the challenges of living in the Anthropocene (UNESCO, 2023). Indigenous communities are well positioned to provide insights into the impacts of climate change and strategies for adaptation as they have successfully managed to navigate the effects of climate change and extreme environmental conditions (IPCC, 2023).

The D-NOSES project understands the importance of integrating local knowledge into project design and work directly with local community networks to empower citizens to become a driving force for change. The SeaPaCS project also aims to support social inclusion and cultural diversity by integrating local knowledge and addressing regional issues identified by the local stakeholders. These approaches which acknowledge the value of multiple perspectives have many advantages in terms of project outcomes from enhancing the richness of datasets (Pateman & West, 2023) to encouraging communities to continue to take action and sustainably address issues at the local level.

Diversity in educational backgrounds which include local knowledge can be supported through the introduction of tiered training programs which cater for different levels of knowledge. Training can improve participant confidence and competence and illustrate the transformative potential of citizen science (Unterfrauner *et al*., 2023). Furthermore, engaging in civic involvement and education through targeted approaches can generate new ideas and innovation to address societal problems. (Hecker *et al*., 2018). These approaches which support inclusivity for people from a variety of educational backgrounds can also play an important role particularly in relation to environmental injustice (Ceccaroni *et al*., 2021). Furthermore, accommodating different levels of scientific knowledge cannot only enhance community learning, but also engagement, as participants have a real opportunity to contribute.

In addition to removing barriers to participation in citizen science projects based on education and alternate knowledge systems, inclusivity from the perspective of accessibility relates to factors including language, physical access, and technology, which have clear and measurable impacts on project design and can extend to access to information, data, and even project results (Heinisch, 2021). A significant issue with regard to accessibility and inclusivity also relates to people with disabilities who face significant challenges in participation in environmental issues and citizen science. For example, although one billion people living with disabilities worldwide have been identified as acutely affected by climate change, they have been excluded from climate change action without consideration for their rights or needs (International Disability Alliance, IDA, n.d.).

The barriers to participation for people with specific accessibility needs in citizen science projects are varied, however, after extensive interviews with Deaf and Hard of Hearing (DHH) adults, the European Commission funded Citizen Science for All (CitSci4All) project, concluded that DHH adults are excluded as they are not aware of these initiatives because of problems with access to information and, more particularly, due to a lack of targeted recruitment. While this reflects the experience of a specific group, it’s analysis can be relevant to any group that is excluded because of barriers to accessibility.

These barriers can be addressed through project design features in multiple ways with varying degrees of complexity depending on the nature of the research and desired project outcomes, however, it can still pose challenges for citizen science projects. For example, the MPOMS project involves remote fieldwork and provides alternate travel options to accommodate participants, however, it’s accessibility challenges are very difficult to overcome for wheelchair bound individuals. Alternatively, the Irish Butterfly Monitoring Scheme can facilitate physical access as each volunteer can individually select accessible routes; however, this is a fortunate byproduct of the nature of the research. In contrast, collaborative projects such as the INCREASE, and D-NOSES initiatives which aim to reach diverse groups over expansive geographical areas strive to facilitate digital accessibility through multilingual online resources and Web Content Accessibility Guidelines (WCAG) 2.2-compliant digital platforms. INCREASE also stress the importance of also using simplified language and D-NOSES provide user-friendly tools like the OdourCollect application, but also offer physical workshops and sensory walks to facilitate wider engagement. In contrast, the SeaPaCS project which prioritises social and cultural inclusion and actively involves the local community through iterative "*collaboratoriums*" may not have encountered accessibility issues in a local environment. This highlights one of the benefits to co-designed projects as communities are best placed to communicate their needs (Yanay-Ventura, 2019).

The benefits to removing barriers to accessibility - in terms of physical access for the D-NOSES project, as well as language and technology in both the INCREASE and the D-NOSES projects - are broader and more inclusive participation which can enhance the quality and diversity of data collected and lead to more inclusive datasets (Nov *et al*., 2010). This can also help produce outcomes that are more representative of a wider range of social and cultural contexts, which makes research findings more applicable to diverse populations and promotes broader community involvement. The use of accessible methods and tools which facilitate full participation from diverse groups, not only increases the ability of all participants to engage and learn effectively, but also increases a sense of belonging and encourages behavioural change (CitSci4All, 2022) and is supportive of sustainable practice.

As the cornerstone to citizen science, the nature of participation is perhaps the most influential aspect of inclusivity in citizen science and significantly impacts the way projects are designed and their outcomes (Shirk *et al*., 2012). Participation can also be understood through the level of involvement at each stage of the citizen science project as well as understanding who will participate. Ensuring genuine inclusivity through the practical application of the "*Leave no one behind*" (LNOB) principle begins with identifying and addressing those who are excluded or marginalised (Munro & Bond, 2018). The United Nations Development Programme (UNDP) framework identifies five key factors contributing to exclusionary processes which include discrimination, geography, governance, socio-economic status, and vulnerability to shocks (Renner *et al*., 2018). Citizen science can help overcome some of these practices through social inclusion and the design of projects which carefully consider the level of participation, ranging from contributory and collaborative to co-designed, and the quality of participation, which determines whose interests will be addressed and how desired outcomes are defined (Shirk *et al*., 2012).

Although each participatory approach in citizen science engages the public, co-designed projects offer the greatest level of involvement for participants. For example, SeaPaCS involves stakeholders throughout the entire project lifecycle to facilitate co-creation so that participants can help identify research priorities as well as co-develop tools and undertake data analysis. ILK is welcomed by the project and is particularly important in relation to co-designed participation, as it supports local agency and authority in project design and decision-making. The D-NOSES project, as another co-designed project, not only seeks to democratise science, restore public institutional trust, and facilitate citizen involvement in regulatory developments by engaging participants at every stage of the project, but also considers individuals as "*co-creators*" who are equally "*co-responsible*" for addressing community issues. This level of participation places citizens on an equal footing and represents true inclusiveness.

These higher levels of participation in co-designed projects lead to more engaged participants and outcomes that are closely aligned with the needs and priorities of communities. Involving participants in shaping the research process is important to produce actionable and locally relevant findings and can also enhance participants' skills and sense of ownership and empowerment in the project (Sardo *et al*., 2022), increase scientific literacy, and build community leadership that can contribute to addressing community-specific issues (Fiske et al., 2019). In contrast, while contributory models can be successful in terms of producing scientifically rigorous data, the research questions are less connected to the needs and interests and daily lives of participants. The lack of participant involvement in decision-making processes can limit the potential for innovation and the development of more context-specific research questions or solutions. In this context, citizen science has an important role to play in terms of social sustainability, as active participation of citizens in scientific research can create a greater connection between people and their environment and encourage a sense of responsibility and agency (Varga *et al*., 2023).

The overall findings of the research suggest that many of the barriers to participation in citizen science projects can be overcome by incorporating demographic diversity into the project design resulting in more representative and richer datasets. This can include developing outreach programs which actively engage local communities and underrepresented groups. Similarly, designing projects for educational diversity which also respects and integrates ILK can improve project outcomes by increasing competence and skills across a broader participant base. This can include developing tiered training programs as these can facilitate multiple backgrounds and support social inclusion and cultural diversity. Inclusivity in terms of accessibility is also an important aspect of inclusivity in citizen science which is often overlooked in project design. Incorporating targeted recruitment strategies and designing projects which are sensitive to the cultural context can address many of the barriers to participation in language, physical access and technology and enhance the quality and diversity of data. Projects that understand inclusivity in terms of co-created participation provide the greatest level of inclusivity resulting in richer and more comprehensive datasets that increase scientific awareness, engagement and opportunities to transition to community-led initiatives that support sustainable practices.

Incorporating co-creation into project design is therefore important to create authentically inclusive citizen science projects which benefit individuals, communities and science. Nevertheless, inclusive practices can also be incorporated in contributory and collaborative approaches that support authentic involvement. Focusing on the relationship between initial conceptions of inclusivity in citizen science and how this impacts on project design and final outcomes, this research has highlighted key points for consideration to support genuine inclusive practice in any participatory model. Building on these insights, these recommendations for inclusivity in citizen science project design are not exhaustive. but can serve as a guide to key design features that supplement the ECSA 10 Principles of Citizen Science to facilitate authentic involvement and support the LNOB principle.

I. Demography: Incorporate targeted recruitment into project design and develop outreach programs that directly engage with underrepresented groups and marginalised communities, as well as established networks, with consideration for the appropriateness of language used and the relevance of the medium and channels employed.

II. Demography: Collaborate with local community groups and organisations for citizen projects at all participatory levels, to facilitate broader participation and engage role models from these communities to encourage participation and diversity.

III. Education: Design inclusive learning experiences in tiered training programs that cater for varying levels of scientific knowledge based on the principles and guidelines of Universal Design for Learning (UDL). Supporting equity, access, and outcomes, these guidelines ensure that all learners can access and participate in meaningful and challenging learning opportunities (CAST, 2024), which can facilitate more substantive opportunities for participants from various educational background to engage in citizen science.

IV. Education: Provide flexible learning through a range of educational resources including, in-person workshops and hands-on training, as well as online courses, to support people from different educational background with various learning needs and styles.

V. Education: Integrate ILK into the project design as diverse "*situational*" knowledge is fundamental to sustainable practice, particularly in relation to climate change action and environmental issues. Traditional knowledge can provide valuable insights for research, enhance the richness of datasets, and increase public institutional trust.

VI. Accessibility: Incorporate the principles of the UN Convention on the Rights of Persons with Disabilities (CRPD) into the project design to ensure that locations and activities are accessible to individuals with disabilities and varying needs, and to support the implementation of sustainable development.

VII. Accessibility: Develop digital platforms that adhere to Web Content Accessibility Guidelines 2.2 (WCAG) to ensure that online content is accessible on desktops, laptops, tablets, and mobile devices. This can help facilitate access for a broad range of users who experience blindness and low vision, photosensitivity, deafness and hearing loss, and limited mobility, as well as cognitive limitations and learning disabilities (W3C, 2023).

VIII. Accessibility: Carefully develop communication and resources using simplified language that is sensitive to the cultural context and avoids the use of unfamiliar language, to increase understanding and facilitate broader participation. This can include scientific terminology and the use of particular words such as "citizen", "science," and "skilled". Language is important in citizen science as it can pose significant barriers that alienate underrepresented communities or marginalised groups. The United Nations (UN) provide a series of recommendations which include the *Guidelines for Gender-Inclusive Language* which aims to prevent discrimination based on sex, social gender, or gender identity (United Nations, 2018), the *Disability-Inclusive Guidelines* which advocates for people-first language (United Nations Office at Geneva, 2019), as well as the *Disability-Inclusive Communications Guidelines* to ensure that communication practices are accessible and inclusive for persons with disabilities (UNPRPD, 2023). Although these recommendations are primarily designed for UN staff, they are publicly available and can be applied across any domain such as citizen science.

IX. Accessibility: Consider providing materials and online or in-person support in multiple languages to ensure that language barriers do not exclude potential participants. Multilingual training enhances learning, improves access, contributes to human dignity, peace and sustainable development and supports intercultural dialogue (UNESCO, 2023).

X. Participation: Design projects to facilitate varying levels of involvement from contributory involvement to co-creation, with multiple entry-points for citizens to ensure that diverse perspectives and knowledge are integrated into the project.

XI. Participation: Establish multiple channels for participants to provide feedback on their experiences, to facilitate community engagement and improve participant experience.

XII. Participation: Organise events and workshops that encourage community involvement and strengthen relationships among participants, enhance social cohesion and collective action.

XIII. Participation: Consider providing financial compensation, where funding allows, to community champions and help overcome the challenges that volunteerism can represent for many community groups.

XIV. Participation: Support sustainable practices through community involvement and future planning to facilitate a transition from researcher-led or co-designed projects to community-centered projects, which empower citizens.

XV. Participation: Design projects for co-creation which involve participation in the design and implementation of projects, to ensure that participant needs and perspectives are considered and integrated into the project, and encourage a sense of ownership and value for volunteers and supports sustainable practices.

As discussed, achieving true inclusiveness in citizen science presents significant challenges as it requires acknowledging and overcoming barriers to participation based on factors including socioeconomic status, education and geographic location. In addition, authentic involvement requires deliberate project design that prioritises demographic diversity, diversity in education, accessibility for all members of society, and meaningful participation. This research and case study assessment of citizen science projects, including initiatives in environmental monitoring, agricultural biodiversity, and ecological systems have highlighted the importance of inclusivity, and explained how different conceptualisations of inclusivity affect the project design and outcomes. It also illustrates the importance of giving careful consideration to the meaning of inclusivity from the outset of a project and embedding this into the project framework. The recommendations based on this analysis offer practical strategies to enhance inclusivity in citizen science and ensure more equitable outcomes. The benefits to including a broader community in citizen science are manifold and not only include more comprehensive datasets, but perhaps more importantly, the promotion of social inclusion, cultural diversity and environmental justice, which are fundamental to navigating life in the Anthropocene and achieving the SDGs.

Table 1: Conceptual framework: inclusivity and demographic diversity in citizen science projects

Type of inclusivity	Description	Assessment indicators	Project design	Relationship between project design and project outcome	Project outcomes	Relationship between project outcome and inclusivity
Demography	Representation of different ages, genders, ethnicities, socioeconomic statuses	Diversity indices, demographic surveys, participation rates by group.	Recruitment and outreach	Targeted outreach strategies to attract a diverse demographic. (Pateman *et al.*, 2021)	Scientific	Diversity increases volume, richness and openness of data (Pateman *et al.*, 2021)
			Methods	Design methods that cater to various age groups, genders, ethnicities. (Shirk et al., 2012)	Community	Enhances community representation and relevance of findings. (Dickinson et al., 2012)
			Training and support	Create training programs that accommodate different education levels and backgrounds. (Dickinson *et al.*, 2012) (Hsu, Kao & Chai, 2023)	Participant	Improves participant engagement and learning outcomes. (Rotman *et al.*, 2012)
			Communication and feedback	Ensure communication is inclusive and accessible to all demographic groups. (Bonney *et al.*, 2009) (Hsu, Kao & Chai, 2023) (Herzog and Lepenies, 2022)	Community	Achieves demographic diversity in participation and feedback loops.

Table 2: Conceptual framework: inclusivity and educational diversity in citizen science projects

Type of inclusivity	Description	Assessment indicators	Project design	Relationship between project design and project outcome	Project outcomes	Relationship between project outcome and inclusivity
Education	Engaging people with varying levels of scientific knowledge and understanding.	Surveys measuring scientific knowledge, educational background of participants, engagement levels in different tasks.	Recruitment and outreach	Engage participants with varying levels of scientific understanding through targeted messaging. (Newman *et al*., 2012) (Land-Zandstra *et al*., 2021)	Scientific	Diverse knowledge can generate new ideas and innovation to address societal problems. (Hecker *et al*., 2018).
			Methods	Design tasks that accommodate different levels of scientific knowledge. (Rotman *et al*., 2012)	Community	Enhances community learning and engagement through varied knowledge contributions.
			Training and support	Provide tiered training programs to suit different knowledge levels. (Wiggins *et al*., 2011)	Participant	Improves participant confidence and competence in contributing to the project. (Unterfrauner *et al*., 2023)
			Communication and feedback	Communicate in a way that is inclusive and aligns with participants motivations (Land-Zandstra *et al*., 2021)	Inclusivity	Ensures diverse knowledge contributions and effective feedback for project improvement.

Table 3: Conceptual framework: inclusivity and accessibility in citizen science projects

Type of inclusivity	Description	Assessment indicators	Project design	Relationship between project design and project outcome	Project outcomes	Relationship between project outcome and inclusivity
Accessibility	Ensuring participation regardless of physical abilities, internet access, and technological literacy.	Participant feedback on accessibility, technology use statistics.	Recruitment and outreach	Develop outreach that ensures access for people with varying accessibility needs (Haklay, 2013)	Scientific	Broadens participation, leading to a more inclusive dataset. (Nov *et al*., 2010)
			Methods	Implement universally accessible methods and tools. (Gray *et al*., 2017) (Kruger *et al*., 2023) (Hsu, Kao & Chai, 2023)	Community	Encourages behavioural change and sense of social belonging (CitSci4All, 2022).
			Training and support	Offer accessible training materials and support systems. (Cohn, 2009)	Participant	Increases the ability of all participants to engage and learn effectively.
			Communication and feedback	Ensure all communication is accessible to participants with different needs. (Lewandowski & Oberhauser, 2016; Jansen *et al*., 2024)	Community	Facilitates full participation and feedback from diverse groups to enhance inclusivity (Fiske *et al*., 2019)

Table 4: Conceptual framework: inclusivity and participation in citizen science projects

Type of inclusivity	Description	Assessment indicators	Project design	Relationship between project design and project outcome	Project outcomes	Relationship between project outcome and inclusivity
Participation	Degrees of involvement including contributory, collaborative and co-designed	Number of participants involved in co-design, levels of decision-making authority among participants.	Recruitment and outreach	Encourage different levels of participation in targeted outreach materials. (Shirk *et al*., 2012)	Scientific	Higher engagement levels can improve data quality and project innovation by answering the needs of science while aligning with the interests of participants. (Haklay, 2013)
			Methods	Provide opportunities for various levels of involvement, including leadership roles. (Bonney *et al*., 2016)	Community	CS projects initiated or run by citizens inherently reflect their social value (Fiske *et al*., 2019)
			Training and support	Offer support that empowers participants to take on leadership and co-design roles. (Shirk *et al*., 2012) (Herzog & Lepenies, 2022) (Sardo *et al*., 2022)	Participant	Enhances participants' skills and sense of ownership and empowerment in the project. (Sardo *et al*., 2022)
			Communication and feedback	Facilitate feedback channels that allow participants to influence project direction and design. (Haklay, 2013) (Nov *et al*., 2010) (Herzog and Lepenies, 2022)	Community	Provide opportunities for various levels of involvement, including leadership roles. (Bonney *et al*., 2009) (Herzog and Lepenies, 2022)

Table 5. How public participants interact with scientists through public participation in scientific research (PPSR)

Projects	**Members of the public**
Contractual	Request scientists to conduct a scientific investigation and report.
Contributory	Requested by scientists to collect and contribute data and/or samples.
Collaborative	Assist scientists in developing a study and collecting and analysing data for shared research goals.
Co-created	Work with scientists to develop a study and address a question.
Collegial	Independently conduct research that advances knowledge in a scientific discipline.

Source: Adapted from Shirk *et al*., 2012.

Table 6: Thematic framework: exploring inclusivity in citizen science projects

Theme	Description	Questions	Measurement
1.Participant demographics	The diversity of participants involved in the project.	What are the demographic characteristics of participants? Age Gender Socioeconomic status	Yes/No
2 Accessibility	Measures taken to make the project accessible to a broad audience.	How accessible is the project for people with disabilities, different language speakers, or limited resources?	Yes/No
3.Educational diversity	How educational diversity is integrated as part of inclusivity efforts within the project.	How does the project address and incorporate diverse educational backgrounds and learning needs?	Yes/No
4.Participation level	Contributory, collaborative, and co-created models.	What level of participation is offered? Contributory, Collaborative Co-created Local knowledge	Yes/No
5.Engagement strategies	Approaches used to engage diverse groups in the project.	What methods are used to actively recruit and engage underrepresented groups? Partnerships Digital Community Academia	Yes/No
6.Training and support	Training and support provided to participants.	What training and support are provided to participants to facilitate their involvement?	Yes/No
7.Feedback and adaptation	Mechanisms for incorporating participant feedback and adapting practices.	How is feedback from participants collected, used and adapted?	Yes/No
8. Evaluation and reporting	How is the project evaluated and reported.	How are results and progress reported? Reports Papers Web	Yes/No

9. Impact on outcomes	How inclusivity affects the outcomes and quality of the project.	In what ways does inclusivity influence the project's outcomes and overall quality?	Assessment score

Table 7: Results

	Irish Butterfly Monitoring Scheme	Malta Pollinator Monitoring Scheme (MPOMS)	INCREASE Citizen Science Experiment	The Distributed Network for Odour Sensing Empowerment and Sustainability D-NOSES	Sea Plastics Consequences Study (SeaPaCS)
1. Demographic distribution	-	-	-	-	-
Age	Unknown	Y	Y	Y	Y
Gender	Unknown	Y	Y	Y	Y
Socio-economic	Unknown	Y	Y	Y	Y
2. Accessibility	-	-			
Language	N	Y	Y	Y	N
Physical	Y	N	N	Y	Y
Technology	Y	Y	Y	Y	Y
3. Educational diversity	Y	Y	Y	Y	Y
4. Participation	-	-			
Contributory	Y	Y	Y	Y	Y
Collaborative	N	N	Y	Y	Y
Co-designed	N	N	N	Y	Y
Local knowledge	N	N	Y	Y	Y
5. Engagement	-	-			
Partnerships	Y	Y	Y	Y	Y
Digital	N	Y	Y	Y	Y
Community	N	Y	Y	Y	Y
Academia	Y	Y	Y	Y	Y
6. Training and support	Y	Y	Y	Y	Y
7. Feedback and adaptation	Y	Y	Y	Y	Y
8. Reporting	-	-			
Reports	Y	Y	Y	Y	Y
Papers	N	N	Y	N	N
Website	Y	Y	Y	Y	Y
9. Total score	10/20	15/20	18/20	19/20	18/20

Data availability statement

The author confirms that the data supporting the findings of this study are available within the document and can be accessed in the case studies and the related results.

These data were derived from the following resources available in the public domain:

I. Irish Butterfly Monitoring Scheme: Information about the project and annual reports can be accessed on the Biodiversity Ireland website (https://www.biodiversityireland.ie).
II. Malta Pollinator Monitoring Scheme: Details about the initiative and related resources are available on the Environment and Resources Authority website (https://era.org.mt).
III. INCREASE Citizen Science Experiment: Information on the project and its progress can be found on the official INCREASE website (https://www.increaseproject.eu)
IV. The Distributed Network for Odour Sensing Empowerment and Sustainability (D-NOSES): Information and updates about the project are available on the D-NOSES website (https://www.d-noses.eu).
V. Sea Plastics Consequences Study (SeaPaCS): Details about the project and its findings are accessible on the SeaPaCS website (https://www.seapacs.org) and (https://calls.ars.electronica.art/2024/prix/winners/10328/).

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APPENDICES

APPENDIX A

Citizen science: selected definitions

1	Oxford English Dictionary (2014)	Scientific work undertaken by members of the general public often in collaboration with or under the direction of professional scientists and scientific institutions
2	Wikipedia (2005)	A project (or ongoing program of work) which aims to make scientific discoveries or verify scientific hypotheses
3	Wikipedia (2019)	Scientific research conducted, in whole or in part, by amateur (or nonprofessional) scientists
4	National Geographic Encyclopedia	Citizen science is the practice of public participation and collaboration in scientific research to increase scientific knowledge. Through citizen science, people share and contribute to data monitoring and collection programs
5	Australian Citizen Science Association	Citizen science involves public participation and collaboration in scientific research with the aim to increase scientific knowledge. It's a great way to harness community skills and passion to fuel the capacity of science to answer our questions about the world and how it works
6	European Citizen Science Association	Citizen Science – the participation of the general public in scientific processes... an open and inclusive approach, for example, by supporting and being part of the exploration, shaping, and development of the different aspects of the citizen science movement, its better understanding, and use for the benefit of decision-making
7	European Citizen Science Association	Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding
8	Citizen Science Association (US)	Citizen science is the involvement of the public in scientific research, whether community-driven research or global investigations
9	Group on Earth Observations Citizen Science Working Group	Citizen science encompasses a range of methodologies that encourage and support the contributions of the public to the advancement of scientific and engineering research and monitoring in

		ways that may include co-identifying research questions; co-designing/conducting investigations; co-designing/building/testing low-cost sensors; co-collecting and analysing data; co-developing data applications; and collaboratively solving complex problems
10	United Nations Environmental Programme (UNEP) (2019)	Citizen science entails the engagement of volunteers in science and research. Volunteers are commonly involved in data collection but can also be involved in initiating questions, designing projects, disseminating results, and interpreting data
11	UNESCO (2013)	The participation of a range of non-scientific stakeholders in the scientific process. At its most inclusive and most innovative, citizen science involves citizen volunteers as partners in the entire scientific process, including determining research themes, questions, methodologies, and means of disseminating results
12	US Crowdsourcing and Citizen Science Act (15 USC 3724) (2016)	The term citizen science means a form of open collaboration in which individuals or organizations participate in the scientific process in various ways, including (A) enabling the formulation of research questions; (B) creating and refining project design; (C) conducting scientific experiments; (D) collecting and analysing data; (E) interpreting the results of data; (E) interpreting the results of data; (F) developing technologies and applications; (G) making discoveries; and (H) solving problems
13	Citizenscience.gov (US)	In citizen science, the public participates voluntarily in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analysing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems
14	US National Institutes of Health	Citizen science efforts are driven by community concerns. These community-led projects may involve a partnership with an academic or research institution, where both parties work together to collect and share data. The goal is to address a community concern through collaborative research

		and to translate the research findings into public health action that benefits the community
15	US Environmental Protection Agency (EPA) (2018)	Citizen science is a form of open collaboration in which individuals or organizations participate voluntarily in the scientific process in various ways, including collecting and analysing data. Citizen science provides a way for members of the public to participate and support EPA programs
16	The US National Aeronautics and Space Administration (NASA)	Citizen science is defined as a form of open collaboration in which individuals or organizations participate voluntarily in the scientific process in various ways. This policy defines citizen science projects as science projects that rely on volunteers
17	US National Oceanic and Atmospheric Administration (NOAA)	Citizen science is defined as a form of open collaboration where members of the public participate in the scientific process to address real-world problems in ways that include identifying research questions, collecting and analysing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems
18	The US National Academies of Science (2018)	The involvement of the broader public in the research enterprise
19	EC Environment (2013)	Citizen science encompasses many different ways in which citizens are involved in science. This may include mass participation schemes in which citizens use smartphone apps to submit wildlife monitoring data as well as smaller-scale activities
20	Socientize (2014)	Citizen science refers to the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources
21	EU (2016)	Inclusion of non-institutional participants, in other words the general public, in the scientific process
22	EU (2017)	Citizen science – where citizens become providers and users of data. This will reinforce and give new meaning to the policy of open access to publications and data; this openness should enable citizens and

		citizen groups to participate in evidence-based policy and decision-making
23	EU (2019)	More and more Europeans hold higher education degrees. Enabled by digitalisation and knowledge, citizens are today prosumers capable of shaping the innovation process and bypassing restrictive practices of established sectors and governments. This goes well beyond citizen science and covers the entire research and innovation process
24	OSPP (2018)	Broadly defined, citizen science is 'scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions'. Citizen science is an already very diverse practice, encompassing various forms, depths, and aims of collaboration between academic and citizen researchers and a broad range of scientific disciplines. Civic participation in research can range from short-term data collection to intensive involvement in the research process, from technical contribution to genuine research, and from collaboration to co-creation of knowledge. Yet, there is still a need to define and establish citizen science as a genuine, open research approach
25	G7 Science Academies (2019)	... Two categories of citizen science. The first one, which is predominant, is participatory research done by citizens who have not necessarily received training in scientific research. It was this activity that has been historically named 'citizen science'... A second and more recent category of citizen science involves scientifically trained individuals working in isolation, or in virtual communities, to develop projects outside established controlled environments (university, government, or industry research system)
26	OECD (2017)	At the heart of the scientific process, it can be more narrowly understood as people, who are not professional scientists, taking part in research, i.e. co-producing scientific knowledge. This involves collaborations between the public and researchers/institutes but also engages governments and funding agencies
27	Science Europe (2018)	The practice of citizens performing science and of scientists working together with citizens

28	LERU (2016)	Citizen science, the active involvement of nonprofessional scientists in research... The boundaries of what can rightly be termed citizen science are debatable, but there is broad consensus that projects should involve voluntary and active public engagement with research
29	RAND Corporation (2017)	Citizen science takes open science activities beyond the purview of professional scientist circles by exploring the involvement of citizens in scientific research and the implications of these activities on and within society
30	Green Paper Citizen Science Strategy 2020 for Germany (2016)	Citizen science describes the process of generating knowledge through various participatory formats. Participation can range from the short-term collection of data to the intensive use of leisure time to delve deeper into a research topic together with scientists and/or other volunteers, to ask questions, and to get involved in some or all phases of the research process
31	UK Parliamentary Office of Science and Technology (POST) (2014)	Environmental citizen science – the involvement of volunteers in environmental monitoring
32	UK Environmental Observation Framework (2012)	Citizen science, broadly defined as the involvement of volunteers in research
33	Nesta (2019)	Citizen science is any process where scientists and the public process scientific data or observations. Citizen science (usually unpaid) volunteers work together to collect or unlock new resources for research, experimentation, and analysis by opening the process to everyone
34	Environmental Science & Technology journal (2007)	According to Wikipedia, the term citizen science refers to a program in which a network of volunteers, many of whom have little or no specific scientific training, perform or manage research-related tasks, such as observation, measurement, or computation

Source: Haklay et al. (2019)

APPENDIX B

Citizen science and inclusivity: integrating Indigenous and Local Knowledge (ILK)

Although citizen science has gained momentum in recent years, there remain significant barriers for participants in non-industrialised and non-Western contexts. Citizen science projects are typically developed in Western, educated, industrialised, rich, and democratic (WEIRD) contexts with little engagement with indigenous communities or alternative epistemological frameworks (Tengö et al., 2021). Furthermore, citizen science seeks to engage individuals in contributing to scientific research within existing scientific knowledge systems, however, ILK systems can make important and valuable contributions to existing knowledge in sustainable ways. This is particularly important in relation to environmental management, as the livelihoods of indigenous people are often reliant on the environment and more negatively impacted by the loss of ecosystem services and extreme weather events (IPCC, 2023).

Representing distinct and complementary knowledge systems, traditional knowledge involves extensive ecological understanding and intergenerational connections relating to the land and people, that have successfully stewarded the natural environment in non-destructive ways for millennia (Tengö et al., 2021). In addition, as the custodians of cultural diversity, indigenous peoples are essential to building learning communities and achieving the 2030 Agenda UNESCO (2018). According to UNESCO (2023), ILK systems contribute to achieving Sustainable Development Goal 13 on climate action through observations of climate changes, as well as adapting to the effects and contributing to mitigation on a global scale.

Acknowledging the value of indigenous knowledge, UNESCO founded the Local and Indigenous Knowledge Systems (LINKS) in 2002 to articulate the importance of local knowledge and support transdisciplinary knowledge cooperation and the participation of indigenous and local communities in multilateral mechanisms. This includes numerous initiatives across multiple themes, such as the Biodiversity and Ecosystems Services (BES-Net) Trialogues which recognise the importance of ILK in guiding biodiversity and ecosystem services policies, and facilitate dialogue between indigenous communities, scientists, practitioners, and policymakers to help build inclusive, locally appropriate policies and conservation actions (UNESCO, 2024).

Integrating ILK into citizen science is therefore important to support cooperation and inclusivity. Based on their research of citizen science projects, Benyei et al. (2023) provide several recommendations to address some of the issues presented in non-WEIRD contexts, which include:

(i) Enhancing local and global connections,

(ii) Co-creating projects with indigenous groups,

(iii) Applying data ethics that do not replicate colonial science

(iv) Using tools that are useful in the local context

(v) Providing funding for participants.

Adopting these practices and integrating ILK into citizen science can lead to more equitable, inclusive and effective environmental and climate solutions.

APPENDIX C

Citizen science and inclusivity: addressing power dynamics

Citizen science also has a role to play in the production of knowledge and power that can support the societal transformations needed to achieve the SDGs. According to Foucault's concept of power/knowledge, both are closely linked and mutually reinforcing (Foucault, 1980). From this perspective, knowledge is never neutral or objective as it is shaped by power relations that determine its value and reinforce these relationships. In the context of participatory science, McAteer and Flannery (2022) argue that insufficient attention has been given to assessing this power/knowledge dynamic, and as a result, community science projects may not only fail to realise their transformative potential, but also reinforce unequal power arrangements which maintain the status quo. Consequently, there is a need to understand and challenge political and power dimensions in participatory science and include power analysis in the project design. This can prevent reinforcing inequities which limit the potential for societal transformation through citizen science (Lemos et al., 2018).