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Review

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Harnessing Community Science to Support Implementation and Success of Nature-Based Solutions

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Abstract: Community science (CS), a type of community-based participatory research, plays a crucial role in advancing wide-reaching environmental education and awareness by leveraging the collective power of volunteer participants who contribute to research efforts. The low barriers of entry and well-established methods of participatory monitoring have potential to enable community participant involvement in applications of nature-based solutions (NbS). However, a better understanding of the current state of community-based approaches within NbS could improve feasibility for researchers and practitioners to implement community-based approaches in NbS. Based on the current literature, we discern five community science approaches that support NbS: (1) Environmental monitoring to determine baseline conditions; (2) Involvement of participants in NbS development and planning through discussions and workshops (i.e., co-design of NbS); (3) Using existing CS databases to support NbS design and implementation; (4) Determining the impacts and measuring effectiveness of NbS; and (5) Participation in multifunctional activities. While there are various avenues of participation, we find that CS-driven environmental monitoring (i.e., actions that involve observing, measuring, and assessing environmental parameters and conditions over time) emerges as a cornerstone of planning, implementing, and maintaining the success of NbS. As the proliferation of NbS implementation continues, future work to integrate community-based monitoring studies in NbS applications has potential, albeit far from guaranteed, to improve place-based and local societal and ecological outcomes.

Keywords: community science; nature-based solutions; environmental monitoring; participatory monitoring

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1. Introduction

Given the growing accessibility of communication, technology, and promotion of environmental sustainability, citizen or community science (CS) emerges as an appealing and multifunctional approach to conservation and restoration initiatives. In the context of nature-based solutions (NbS)—a concept that focuses on leveraging natural ecosystems to tackle environmental and social issues—it is important to actively engage the public or community members (i.e., affected parties) in assessing the viability and implementing these solutions. This engagement not only gives the public a voice in decisions that impact them directly but positions them at the center of the process rather than merely at the receiving end. Modern CS approaches have been encouraged in many scientific disciplines, enabling large-scale data collection [1] while supporting public scientific education, environmental stewardship [2], and creating opportunities to engage with local communities who are often the recipients of benefits (e.g., provisioning of food and water, regulating natural hazards, protection of cultural heritage, and maintaining biodiversity) from the ecosystem (also termed as ecosystem services) [3]. The terms "citizen scienc". and "community scienc". are intertwined. "Citizen scienc". typically describes projects that benefit scientists (i.e., aims to answer research questions), while "community scienc". may be better suited to grassroots projects that benefit community members (i.e., solving problems identified by communities) [4]. The emphasis of community science is on building relationships, fostering trust, and empowering communities. This type of engagement is developed to address local concerns and leverages the knowledge and resources within a specific community to contribute to scientific inquiry. While citizen science usually involves the public with a broader scope of participation, both citizen and community science may include participants of various backgrounds and levels of expertise and can make meaningful contributions to scientific research. In the context of this review, we consider both terms interchangeable and functioning to democratize science and address real-world issues through participation and scientific literacy. The term "community scienc". (CS) will be used hereinafter as both unless a specific distinction is required in presented cases/methods. Here, we look to Bonney, Ballard [5] to distinguish CS forms of engagement as follows:

(1) Contributory projects (where scientists design and citizens contribute);
(2) Collaborative projects (where scientists design, citizens contribute data, refine project design, analyze data, and/or disseminate findings); and
(3) Co-created projects (where scientists and the public work together, and some public participants have a more active role throughout the scientific process).

The third form of engagement, co-creation, provides an equal platform of inquiry and creativity between citizens and scientists in developing solutions for environmental restoration efforts and creates more buy-in among local stakeholders [3,6]. Adoption of co-creation in NbS projects can result in a wide range of public understanding impacts [2], providing a conduit for knowledge sharing and education between scientists, governance and policy actors, organizations, and community members. Collective actions and responsibilities developed through community-based monitoring (CBM) and participatory research can decolonize conventional relationships between university researchers and Indigenous communities [7]. CBM has been used as a tool for asserting Indigenous sovereignty and jurisdiction, enabling the practice of stewardship and data gathering related to water quality [8], fish toxicology [9], and biodiversity and land change [10], which can inform planning and decision-making around NbS. As stewards of the land, Indigenous peoples and local communities hold knowledge that can support positive and lasting NbS outcomes [11].

Growth and interest in CS initiatives reflect a strong societal interest in actively contributing to knowledge creation and decision-making [12]. Advancements in user-friendly monitoring tools and technologies (e.g., in visual observation through photography, videography, and remote sensing), proliferation of public environmental education, and the numerous forms of participation have revolutionized CS [13]. While it is a means for overcoming data scarcity [14], CS is also often a path for exposure to social activity in the natural environment, and it is an effective way to engage individuals and communities [15] alongside developing changes in attitudes and behaviors that positively impact environmental conservation [16]. Increasing technical and technological competency is expected to advance possibilities in community-based approaches, which, in turn, can lead to a greater adoption of CS. For instance, the use of DNA source tracking in recreational water monitoring (which typically requires scientific expertise and lab resources) shows high reproducibility between non-expert field users and expert laboratory results [17]. While the growth of CS has been observed largely through ecological monitoring with the help of online data collection platforms (e.g., iNaturalist.org, WaterRangers.com), the contributions of CS for various applications of NbS have not been formally presented in a way that can facilitate the use of applications/methods for citizens and community groups.

While many in the scientific, political, and public citizen communities are enthusiastic about the concept of NbS, there is known to be a "general lack of understanding of the multiple benefit". of NbS [18], potentially leading to confusion or greenwashing on the NbS concept. Hence, there is an invaluable opportunity to support communities by listening, taking direction, and learning from historical and current ecological and social contexts before pursuing more complex NbS implementation (i.e., green infrastructure design) that increases public awareness, and along the ladder of participation [19], consultation (inviting citizen's opinions) and partnership (sharing decision-making responsibilities). To date, the authors have not found a literature review examining the use of CS in various types of NbS. In the context of NbS, the range of participation in CS projects can vary, from collecting input and opinions from the public to understand the implications of NbS for day-to-day lives (e.g., measuring ecosystem services that improve human health, such as improved water or air quality, or cultural services such as esthetic green space), planting native tree and plant species to support local biodiversity, to using complex monitoring tools and technologies (e.g., hydrological monitoring, environmental DNA collection, etc.). Examples of intensive community participation extend from monitoring wildlife [20,21] and environmental parameters like soil and water quality [22,23], to understanding the perceived benefits of biodiversity conservation [24], all of which are ways to monitor ecosystem health (i.e., biodiversity, physical and chemical environment, human wellbeing, etc.). This narrative review aims to highlight CS as a driver for NbS implementation and development. The growing interest among community members in participating in scientific inquiry and investigations serves as a catalyst for the advancement of NbS, ultimately addressing the societal challenges that directly impact communities. This review also proposes a range of potential CS environmental monitoring methods that can be used through CS to evaluate the success of NbS. We aim to provide context and considerations for community groups and participants of community science on their role for NbS planning and implementation.

1.1. Considering CS in NbS Typologies

When examining NbS, which cover a broad spectrum of approaches and strategies, various typologies offer granularity and flexibility to examine how major societal challenges can be addressed by working with ecosystems [25], whether it is through management approaches established using policy and legislation (e.g., establishing protected areas) or grassroots conservation initiatives (e.g., community-based reforestation and urban greening). While the concept of ecosystem services and NbS (particularly when looking at how NbS can address societal challenges) can be critiqued as anthropocentric [26], we promote the immense role of people (as both positive contributors and beneficiaries) to the natural environment. NbS offer a range of sustainability benefits that aim to reduce the consumption of natural capital which allows for both economic development and ecosystem stewardship [27]. Current research is limited to examining levels of participation in NbS [28,29] and overlooks CS as a critical component of NbS. It is important to identify success factors for designing stakeholder engagement methods that are appropriate for the local environment and recognize the use of local inputs for decision-making [30]. Here, we utilize two common NbS typologies to examine potential CS activities that can be integrated in existing frameworks.

1.1.1. The Role of CS in the NbS Interventional Typology

The typology presented by Eggermont et al. [31] is commonly used in NbS guides (e.g., ThinkNature Nature-based Solutions Handbook [32], IUCN Global Standard for Nature-based Solutions [33]) to classify solutions based on the level of engineering or management applied (x-axis), the number of ecosystem services and stakeholder groups impacted, and the maximization of the delivery of key ecosystem services (y-axis) (Figure 1). The definition and examples of the three NbS types of Eggermont et al. are presented below and are related to CS examples in the following text.

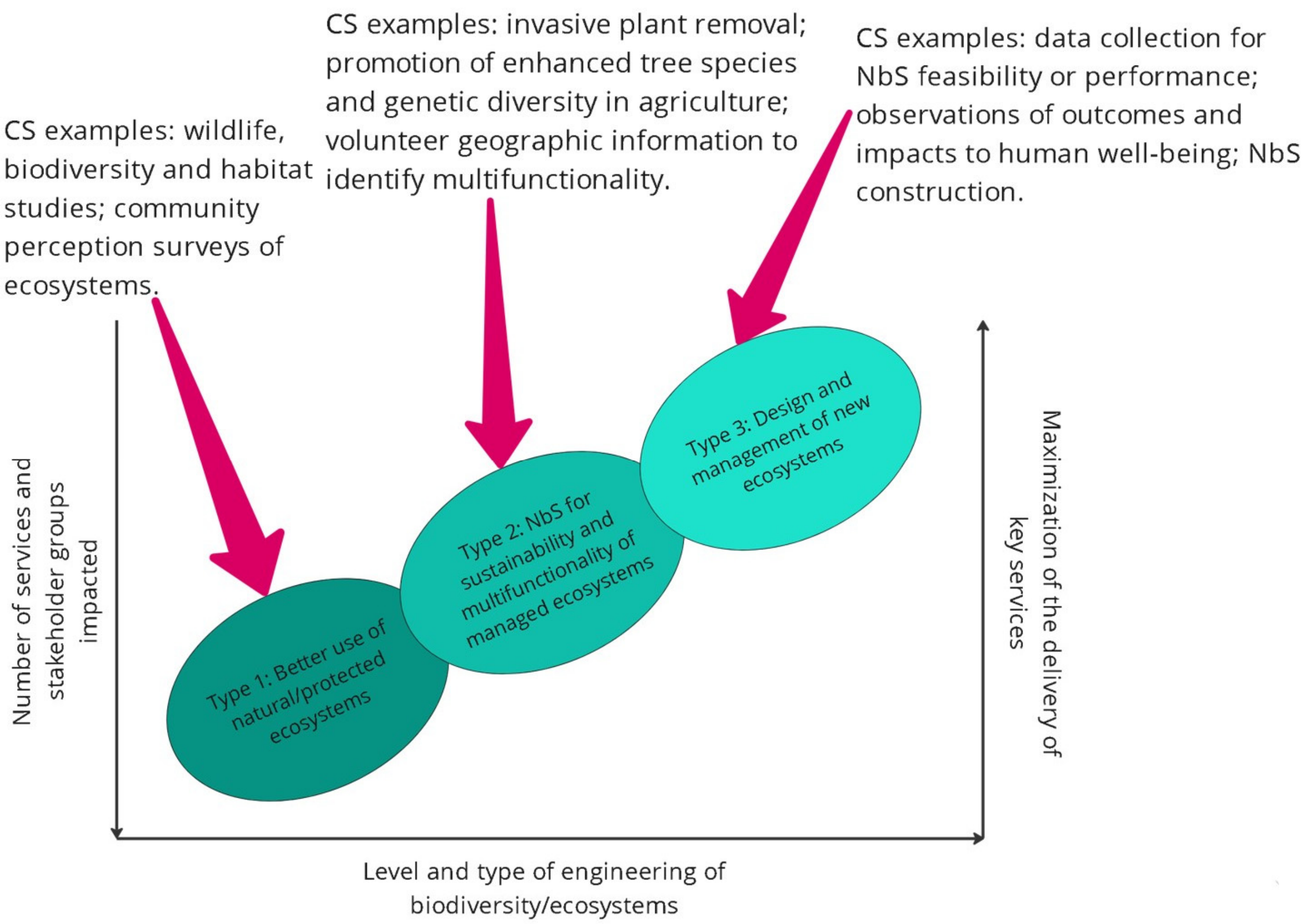

Figure 1. Examples of CS activities that support types of nature-based solutions. Adapted from Eggermont et al. [31].

Type 1 "consists of no or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a range of ES both inside and outside of these preserved ecosystems". For example, climate resilient coastal mangrove protection to provide benefits and opportunities to local populations [34]; and the establishment of marine or forest protected areas to conserve biodiversity within these areas.

Type 2 "corresponds to the definition and implementation of management approaches that develop sustainable and multi-functional ecosystems and landscapes (extensively or intensively managed), which improves the delivery of selected ES compared to what would be obtained with a more conventional interventio". For example, enhancing multifunctionality of agricultural landscapes; enhancement of tree species and genetic diversity to increase forest resilience to extreme events; approaches related to concepts of agroecology and natural systems agriculture; and invasive plant management approaches [35].

Type 3 "consists of managing ecosystems in very intrusive ways or even creating new ecosystems". This type is "linked to objectives like restoration of heavily degraded or polluted areas". For example, artificial ecosystems with new assemblages of organisms for green roofs and walls to mitigate city warming and clean polluted air; and novel approaches such as animal-aided design which aims to to bridge the gap between biodiversity conservation and landscape architecture [31].

This proposed typology suggests that as efforts aim to target a greater number of services and stakeholder groups (such as local government and residents, academics, and environmental groups/organizations), the ability to maximize the delivery of each service decreases, alongside the challenge of meeting the specific needs of all stakeholder groups simultaneously. From this classification, we posit that the consideration of CS is crucial in increasing the number of services and stakeholders impacted and influencing both the maximization of delivery of key services and the level and type of engineering biodiversity/ecosystems. For example, we expect that incorporating CBM and involving residents in the design and construction of urban green infrastructure (considered a Type 3 NbS) will increase the number of services (e.g., cultural services such as supporting public awareness and knowledge on ecosystem processes) and stakeholders impacted, further maximize delivery of services (e.g., community participants can receive and contribute to the development of provisioning and cultural services than would otherwise occur if no participants were involved), and have an influence on the type of biodiversity engineering being considered. On the opposite end of the range, integrating community partners' perceptions, observations, and visions (or envisioned ideals) of threatened species to establish a forest protection area (considered a Type 1 NbS) further maximizes services such as spiritual and religious values (e.g., sacred forests and landmarks), and habitat provision (e.g., diverse habitats supporting wildlife); inspires opportunities and plans for ecological engineering (e.g., bioremediation of contaminated areas); and increases the number of stakeholders impacted through community engagement.

1.1.2. Typology Considering NbS Benefits and Functions

Anderson and Gough's [36] typology classifies five approaches that consider the benefits and functions of various NbS based on the United Nations Sustainable Development Goals (UN SDGs): (1) ecosystem-based protection approaches, (2) ecosystem restoration approaches, (3) issue-specific ecosystem-related approaches, (4) infrastructure-related approaches, and (5) ecosystem-based management approaches. Functions for specific examples of NbS within these five categories are examined, and the UN SDGs are presented as a potential measure for success. Here, we present potential CS actions that can function to enhance these five NbS approaches:

A. Ecosystem-based Protection Approaches (e.g., area-based conservation, protected area management):

- Monitoring and Surveillance: Engaging local communities in monitoring and surveillance activities can help detect environmental changes early, such as habitat degradation, and invasive species.
- Advocacy and Policy Support: Community scientists can advocate for policy changes based on data collected, supporting conservation initiatives and protected area management.

B. Ecosystem Restoration Approaches (e.g., ecological restoration, ecological engineering, forest landscape restoration):

- Data Collection and Analysis: Community scientists can assist in collecting data on biodiversity, soil health, and water quality to evaluate the success of restoration efforts.
- Implementation and Maintenance: Involving local communities in restoration projects promotes stewardship and ensures long-term sustainability of restored ecosystems.

C. Issue-specific Ecosystem-related Approaches (e.g., ecosystem-based adaptation, ecosystem-based mitigation, ecosystem-based disaster risk management):

- Targeted Data Collection: Community scientists can target specific issues such as air or water pollution by collecting data on pollutant levels in collaboration with scientific experts.
- Education and Awareness: CS programs can educate and raise awareness among local communities about the importance of ecosystems and their role in providing protection against natural hazards and disasters.

D. Infrastructure-related Approaches (e.g., natural infrastructure, green infrastructure):

- Green Infrastructure Monitoring: CS can monitor the effectiveness of green infrastructure projects (e.g., green roofs, rain gardens) in mitigating urban heat islands or reducing stormwater runoff.

- Community Engagement in Design: Involve community scientists in the planning and design stages of infrastructure projects to ensure they meet local needs and maximize ecological benefits.

E. Ecosystem-based Management Approaches (e.g., integrated coastal zone management, integrated water resources management):

- Local or Traditional Ecological Knowledge: Indigenous peoples and local community participants often possess local or traditional ecological knowledge that can complement scientific research and inform management decisions.
- Participatory Decision-making: Engaging communities in monitoring and decision-making processes fosters trust and ensures that management strategies align with local priorities.

1.2. The Role of CS in the NbS Co-Benefits Framework

A common characteristic associated with many definitions of NbS is the provision of co-benefits, such as "the improvement of place attractiveness, of health and quality of life, and creation of green job". [37]. A seven-stage process to situate co-benefits within policy and project implementation is presented by Raymond, Frantzeskaki [37], which includes the following: (1) Identify problem or opportunity; (2) Select and assess NbS and related actions; (3) Design NBS implementation processes; (4) Implement NbS; (5) Frequently engage stakeholders and communicate co-benefits; (6) Transfer and upscale NbS; and (7) Monitor and evaluate co-benefits across all stages. While it is possible to connect community approaches in each of these stages (e.g., collecting community input in determining problems or opportunities for stage 1, or engaging community members on understanding and monitoring co-benefits across multiple stages for stages 5 and 7), we are in the early stages of defining the real co-benefits of NbS in the short and long term when involving active participation of community members. Procedures to understand how NbS work as a "complex interventio". and the "multiple co-benefits that can be leveraged if strategically applie". [36] have been studied.

Nature-based CS is a mechanism through which people can be exposed to the natural environment (NE) through "systematic, organized, and scalable activit". [15]. While not all collaborative multi-stakeholder forms of engagement will lead to enhanced ecological functions, strengthened social outcomes, such as "social learning, enhanced sense of belonging, environmental stewardship, and inclusiveness and equit", are examples of benefits from deeper forms of engagement, which is often what NbS set out to have [29]. Active and passive (e.g., reflective activities) CS participation in NbS may provide pathways to supporting socially deprived communities, developing social cohesion, while creating positive returns for nature [38]. Insights on participatory components of environmental and nature-based CS initiatives established in the last two decades indicate that the main driver of CS initiatives for NbS are through academic institutions and that the expansion of digital technologies will improve the control and quality of data collection by community participants [39]. Exploring these established and evolving participatory methods can help overcome obstacles in designing and implementing NbS.

2. Methods

We conducted a narrative literature review to identify common CS approaches in existing NbS publications. We extracted the literature from the two databases to include scientific articles with titles and abstracts containing the keywords "nature-based solution". and a number of community science terms, such as "community scienc", "participatory monitorin", and "community-based monitorin". (see search criteria in Supplementary Materials). The literature from the databases was also scanned based on common examples and approaches of NbS published in the literature from the International Union for Conservation of Nature (IUCN).

Based on the review of paper abstracts, we selected 19 case examples to represent what we propose are five overarching CS approaches observed in the NbS-related literature

(Table S1, Supplementary Materials). Having examined the literature, we expected the intersection of CS and NbS to primarily feature participatory monitoring studies. Accordingly, 61 studies that relate environmental monitoring (categorized into biodiversity-, water-, and soil-related studies) to types of NbS were isolated and presented.

Lastly, we propose how CS activities can be used as metrics for NbS success and in addressing societal challenges. We provide specific links to individual resources for these NbS success metrics in Table S1 (Supplementary Materials) to promote the use of CS in NbS. This narrative review highlights existing approaches for CS in NbS, asserting the necessity of community-based approaches to advance the development, implementation, and, ultimately, the success of NbS.

3. Results and Discussion

3.1. The Use of CS in NbS Planning and Implementation

The use of CS in NbS has been demonstrated to create positive outcomes by fostering public education [29,40], increasing buy-in from citizens on environmental stewardship [41,42] and supporting professional scientists in accomplishing research methods that are otherwise cost-prohibitive [43,44]. The opportunities to involve CS in NbS projects are as wide as the possibilities of NbS designs and programs as reflected in our search. By connecting the term "nature-based solution". with terms associated with CS, we present five overarching CS approaches used in NbS, as exemplified by twenty studies. We also determine the stage(s) of NbS planning and implementation that the CS approach aligns with (i.e., identification of challenges that NbS can address, creating visions and scenarios using NbS to address challenges, and realizing NbS and monitoring outcomes) [45] (Table 1). The five approaches of CS used in planning and implementation of NbS that we have identified emerge from the current literature and are described in the following Sections 3.1.1–3.1.5.

Table 1. CS approaches used in NbS.

CS Approaches Used in NbS	**Example of Study**	**NbS Planning and Implementation**			**Summary of Approach**
		Understand Challenges	**Create Visions and Scenarios**	**Realize and Monitor**	
Monitoring baseline of environmental parameters	Implications of urban land management on the cooling properties of urban trees: Citizen science and laboratory analysis [46]			✓	Citizen scientists gathering data and fresh leaf and shoot samples to investigate the impact of growing conditions set by land and tree management practices in urban environments.
	Science & technology agenda for blue-green spaces inspired by citizen science: case for rejuvenation of Powai Lake [47]	✓		✓	Water quality monitoring program by citizen scientists leading to the development of a lake rejuvenation plan.
	Evaluation of the impacts of land use in water quality and the role of NbS: A citizen science-based study [48]	✓			Citizen-based monitoring of physical and chemical water quality parameters, nutrient analysis, and sample collection for bacteriological analysis to determine NbS potential for the regulation of water quality of a major freshwater reservoir.
	Collaborative 3d monitoring for coastal survey: Conclusive tests and first feedbacks using the SELPhCoAST workflow [49]	✓			Citizen-based coastal erosion monitoring using a smartphone application (in situ photo datasets) to facilitate NbS approaches for local coastal restoration and protection policies.

Table 1. *Cont.*

CS Approaches Used in NbS	Example of Study	NbS Planning and Implementation: Understand Challenges	NbS Planning and Implementation: Create Visions and Scenarios	NbS Planning and Implementation: Realize and Monitor	Summary of Approach
Monitoring baseline of environmental parameters	Implementing participatory nature-based solutions in the Global South [50]	✓	✓		Citizen scientists collecting a comprehensive photo archive of flood levels informing the design of constructed wetlands.
	Nest aggregations of wild bees and apoid wasps in urban pavements: A 'street life' to be promoted in urban planning [51]	✓	✓		Citizen science approach to investigate the richness of ground-nesting species living under urban pavements and preferences for sidewalk pavements to propose urban management guidelines supporting pollination.
	Ecosystem services evaluation of nature-based solutions with the help of citizen scientists [52]		✓	✓	Citizen science approach to collect qualitative and semi-quantitative water quality measurements of a major Italian water catchment under different NbS scenarios. The benefits of nutrient transport with respect to the costs of individual and combined NbS approaches were estimated.
Involvement of participants in NbS development/planning (co-design of NbS to address societal challenges)	Resilience assessment workshops: A biocultural approach to conservation management of a rural landscape in Taiwan [53]		✓		Eliciting a community-driven vision to enhance landscape resilience.
	Including local knowledge in coastal policy innovation: comparing three Dutch case studies [30]		✓		Participants asked to co-design utopic and dystopic visions on long temporal scales and were presented and linked to coastal management strategies toward shared futures.
	The circular benefits of participation in nature-based solutions [38]	✓	✓	✓	Observational and intellectual reflection by participants experiencing NbS to identify benefits to local needs.
	The role of green infrastructure in enhancing microclimate conditions: A case study of a low-rise neighborhood in Abu Dhabi [54]	✓	✓		On-site measurements of tree physical characteristics, air temperature, and geotagging with the use of technology to determine ideal urban tree species for urban cooling effects in Abu Dhabi.
Utilizing existing citizen science platforms and databases	Citizen science data to measure human use of green areas and forests in European cities [55]; Harnessing iNaturalist to quantify hotspots of urban biodiversity: the Los Angeles case study [56]	✓	✓		Utilizing iNaturalist citizen science data to support sustainable development by spatial planning and conservation.
	Climate Change Adaptation in Africa, Asia, and Europe with the Citizen Science Climate Scan Platform Promoting Nature-Based Solutions [18,57]	✓			Online citizen science platform ClimateScan as a tool to stimulate stakeholder engagement and NbS promotion.
Monitoring effectiveness of NbS infrastructure, soliciting feedback from community members on impacts of NbS	When It Rains, It Pours: Integrating Citizen Science Methods to Understand Resilience of Urban Green Spaces [23]			✓	Citizen scientists measuring infiltration rates and soil characteristics in managed and unmanaged green spaces. Advocates for citizen action to improve local green space infiltration and support local flood resilience.

Table 1. *Cont.*

CS Approaches Used in NbS	Example of Study	NbS Planning and Implementation: Understand Challenges	NbS Planning and Implementation: Create Visions and Scenarios	NbS Planning and Implementation: Realize and Monitor	Summary of Approach
Monitoring effectiveness of NbS infrastructure, soliciting feedback from community members on impacts of NbS	Green Infrastructure Mapping for Adaptation, Biodiversity, and Health and Wellbeing: A Tool Development Case Study in Edinburgh [58]			✓	Green infrastructure mapping using CS to collect vegetation type and blue space data for adaptation, biodiversity, and health and wellbeing.
	Volunteered information on nature-based solutions—Dredging for data on deculverting [59]	✓		✓	Collection of geo-reference locations and addresses of daylighting cases and investigation of drivers for deculverting.
Integrated CS and participation in multifuctional activities	Advancing equity and justice through CS programming in design, construction, and research of a nature-based solution: the Duwamish Floating Wetlands Project [60]	✓	✓	✓	Wide diversity of community members participated in the construction and field and lab monitoring of NbS (floating wetlands), resulting in significant contributions to NbS and possible long-term impacts on participants and the environment.
	Nature Based Solutions on the river environment: an example of cross-disciplinary sustainable management, with local community active participation and visual art as science transfer tool [61]	✓	✓	✓	Social and cultural events (public debate, art exposition, performance, and workshops in the experimental field) were organized during the scientific component of a phytoremediation project for a riparian area resulting in policy recommendations for NbS implementation.
	Sediment management using bandal-like structures as nature-based solution [62]	✓	✓	✓	Integrated NbS approach to sediment management involving local community in initial consultations, and construction and monitoring of NbS.

3.1.1. Environmental Monitoring to Determine Baseline Conditions

Monitoring baseline environmental parameters is the most common function of CS programs. Determining the effectiveness of an NbS requires a baseline of human wellbeing and biodiversity benefits, to understand if societal challenges are being addressed. Some outlined cases indicate the use of CS to gather vegetation and forest data, watershed quality data, flood levels, and species richness, which all play a role in evaluating impacts to the ecosystem. CS approaches for monitoring have led to the development of management guidelines that can be considered Type 2 NbS. For instance, Noël et al. [51] investigated pollinator species using a citizen science approach to develop management guidelines to support nesting species in urbanized areas. Monitoring approaches play a key role in challenge identification and can be used for improvement of ecosystem services after implementation of NbS (more on this in Section 3.1.4). In some cases, simple citizen science monitoring programs act as a catalyst for more complex scientific studies investigating NbS. In the case of Best et al. [14], investigations in urban green space cooling using CS monitoring led to the mitigation strategy development of heat-related health risks in the tropics. While more resources may be required to organize involvement for CSs, community-based data collection through environmental monitoring approaches may create the most opportunities for participants to raise awareness and develop visions and ideas of NbS [48].

3.1.2. Involvement of Participants in NbS Development and Planning Through Discussions and Workshops (Co-Designing Processes)

The involvement of participants in NbS development and planning is often presented as community mapping, workshopping, and involves creative outputs of community members. Utilizing the knowledge of community members who are directly impacted by potential NbS programs and creating community-driven visions facilitate identification of existing societal challenges that proposed NbS may address. These co-creative processes foster innovation by recognizing the needs and expectations of impacted community members. Engagement may also identify community preferences in prioritizing a range of solutions, from highly engineered solutions to nature-based solutions [63].

3.1.3. Using Existing CS Databases to Support NbS Design and Implementation

Numerous publicly available citizen science databases exist, namely for biodiversity monitoring (e.g., eBird, iNaturalist, The Great Backyard Bird Count), weather observation (e.g., Citizen Weather Observer Program (CWOP), Old Weather, ClimateScan, Community Collaborative Rain, Hail & Snow Network (CoCoRaHS)), air quality (e.g., AirVisual Earth), land cover and use (e.g., GLOBE Observer, Land Cover Classification System (LCCS), OpenStreetMap (OSM), Mapillary), and water quality and quantity parameters (e.g., Lake Observations by Citizen Scientists & Satellites (LOCSS), Surfrider Foundation's Blue Water Task Force, The Riverkeeper Network, The Global rivers Environmental Education Network (GREEN), World Water Monitoring Challenge). These public databases and volunteer-led programs provide a significant resource for baseline environmental measurements that can support identification of societal challenges that NbS can address. Despite not directly working with community participants, researchers have used these databases to develop models to inform place-based conservation prioritization [56] and create avenues to increase awareness for water conservation and management [57]. Studies that have used CS databases and platforms stimulate stakeholder engagement and NbS promotion.

3.1.4. Monitoring Effectiveness of NbS Infrastructure, Soliciting Feedback from Community Members on Impacts of NbS

Community members are integral to assessing the impacts and success of implementing nature-based solutions (NbS) because they directly experience the benefits of NbS initiatives. Typically, the proximity of community members to realized NbS, such as urban green infrastructure, facilitates a more accessible assessment of the benefits for those affected. Involving community participants in monitoring and evaluation of NbS can develop continuous buy-in and spark co-creation opportunities [11]. Volunteer-based identification and mapping of urban green infrastructure (GI) using a smartphone application [58], as well as monitoring GI status through discrete measurements (e.g., infiltration tests) and more complex sensor systems [64] demonstrate key activities in ensuring effective NbS. Wild, Dempsey [59] highlight the role of volunteered information in understanding local activities and contexts to support future NbS applications. CS has also been used as a tool to facilitate exposure to the natural environment in urban areas, potentially presenting psychological and immunological benefits [15,65,66].

3.1.5. Participation in Multifunctional Activities

While it would be ideal to implement CS throughout an NbS project to take advantage of local capacity and promote environmental stewardship and education, there are few projects that can coordinate these programs successfully. Our search indicates cases where community participants make up the primary workforce for the planned and implemented NbS. As such, participants were not only involved in the planning and consultation stages, but also in its construction and maintenance. Some projects rely on local and generational expertise to construct NbS structures [62], while some have integrated CS to include prototype creation, field measurements, and mentorship programs [60]. Intensive community participation throughout an NbS project also allows opportunities to engage in a broader range of disciplines and can cater to the interests of various participants. One CS program found success by incorporating social and cultural events, and opportunities for scientific data collection, resulting in the development of a policy recommendation regarding phytoremediation [61].

3.2. Expanding on Types of Environmental Monitoring Through CS to Enhance NbS Planning and Implementation

In the previous section of this paper, we found that environmental monitoring emerges as a prevalent participatory activity in the reviewed NbS literature. The next stage of this review identifies themes of environmental monitoring that can inform types of NbS based on the considerations of engineering or management applied to biodiversity and ecosystems, the range of ecosystem services to be delivered, the number of stakeholder groups involved, and the expected delivery of targeted ecosystem service, as presented by Eggermont et al. [31]. We present published CS studies into common themes of biodiversity monitoring, soil-related monitoring, and water-related monitoring, based on their prevalence in the reviewed literature (Figure 2). Considering the relevant role of environmental monitoring and the importance of determining a baseline of observable parameters in the literature, we set out to characterize the common themes and examples of participatory environmental monitoring. When we mapped NbS CS approaches to the Eggermont et al.'s typology, we determined that each CS plays a role in all types of NbS (Figure 2).

For example, in the case of a Type 3 NbS, green infrastructure or artificial ecosystem development (e.g., living docks, oyster gardens, and artificial shorelines), CS that can support effective application of the NbS will benefit from measuring species richness of a water ecosystem (biodiversity monitoring) and measuring aquatic biological indicators through invertebrate sampling, benthic algal growth, and benthic oxygen demand (water-related monitoring). The localized nature of implementing increasingly engineered solutions alongside maximizing delivery of key services may explain why more CS monitoring functions support Type 3 NbS. Specialized monitoring and CS projects particularly targeting urban areas, which are often features of Type 3 NbS, promote early detection and rapid response processes to new species invasions in populated areas [67].

In the case of a Type 2 NbS, the example of adaptive forestry or innovative agricultural management (e.g., eliminating invasive plant species and diversifying vegetation for cattle to support landscape ecosystems), habitat, and physical environmental parameters like soil decomposition rates (soil-related monitoring) are opportunities that can effectively support development of adaptive forestry and have been performed by community scientists. While there are disciplines with more established frameworks for public participation such as biodiversity and water quality monitoring, topics such as forest monitoring have limited CS frameworks [68]. As the level and type of engineering of biodiversity/ecosystems increase, as per Eggermont et al.'s (2015) NbS typology [31], there appear to be more opportunities to implement approaches from the three citizen science monitoring examples listed. For example, in the case of green stormwater infrastructure as an NbS, we expect many opportunities in all three themes of monitoring, from determining species richness, enabling reintroduction of native species, to monitoring the water quantity and quality of runoff and physical soil characteristics for potential built interventions. This increase in opportunities for CS aligns with the proposed increased number of services and stakeholder groups involved the further away you are from a Type 1 NbS.

While what is presented is just a present glimpse of CS monitoring techniques related to publications on the term "nature-based solution", it serves to present potential monitoring opportunities for themes that have not presented as many cases (i.e., soil/land-related monitoring) and that should be adapted to further support the planning or implementation of NbS.

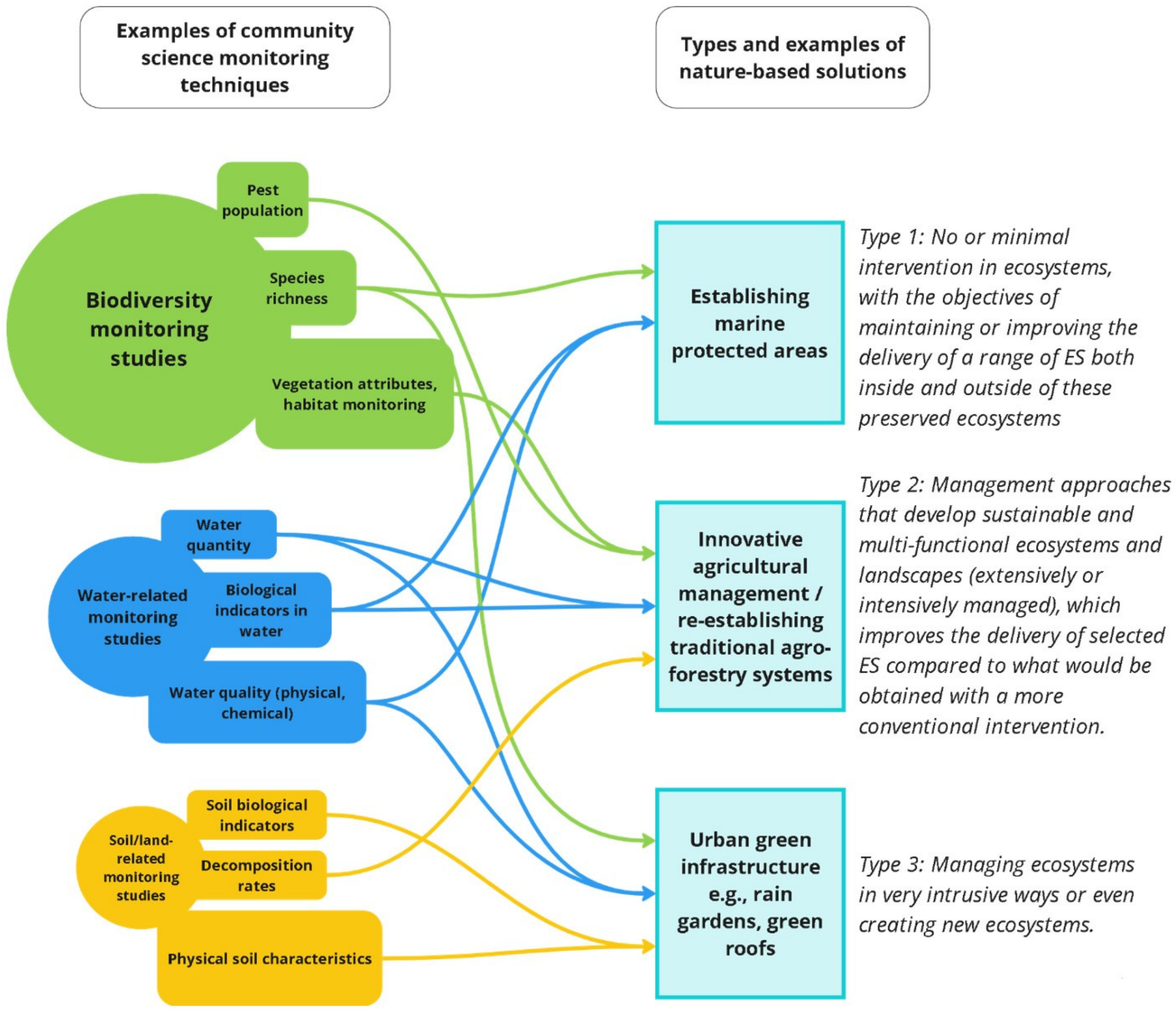

Figure 2. Various monitoring techniques play a role across all types of NbS applications. Biodiversity-related monitoring is the most prevalent in the literature where NbS and CS intersect, followed by water- and soil/land-related monitoring.

3.3. Participatory Monitoring as a Factor of Success for NbS

With increasing opportunities to involve CS in NbS implementation, it will be valuable to recognize and determine these successes or impacts of community participation. The IUCN offers eight criteria to evaluate the desired outcomes of NbS in solving one or several societal challenges [33], and here, we have selected to examine the first criterion as it is in line with the prevailing definition of NbS and positions the use of CS to assess the success of the solutions.

Criterion 1: NbS effectively address societal challenges, i.e., the selection process of NbS is according to the societal challenges (such as water security, food security, human health, disaster risk management, and climate change) they are meant to address and includes their benchmarking and periodical assessment.

Community involvement and participation can be a fundamental component in determining how societal challenges are addressed by NbS, considering that community participants are likely to be directly affected (either negatively or positively) by NbS. Based on the identified societal challenges, as presented in the IUCN Global Standard [33], we present a non-comprehensive list of NbS success metrics that can be supported by CS approaches (Table 2). The authors note that the examples of CS approaches can also be examined based on their feasibility in application (i.e., if the method is feasible based on a wide range of suitable participants, technical or procedural complexity, or financial resources required for a method). We find that the success of NbS in addressing a range of societal challenges can be examined with the use of CS approaches.

Table 2. Non-comprehensive list of measurable success metrics using CS to address societal challenges. NbS success metrics are not exclusive to one type of social challenge and may overlap with one another (e.g., water quality metrics may be evaluated to address the societal challenge of water and food security and climate change). See Table S2 (Supplementary Materials) for weblinks to CS examples and resources.

Societal Challenge [33]	NbS Success Metrics	CS Examples and Key Resources
Water security	Water quantity (e.g., water levels, source identification, flow conditions)	Use of flow meters and probes, top setting wading rods, bucket wheel water current meter, reading flow gauges
	Water quality (e.g., physical, chemical, biological parameters in freshwater, stormwater, marine water, groundwater)	Visual observation (color, presence of algae, macrophytes, presence/absence of trash), quantitative measurements TDS green, pathogen and chemical pollutant monitoring, community-based quantitative polymerase chain reaction (qPCR) to screen for fecal indicator organisms.
	Watershed mapping to improve accuracy and detail of watershed maps and features, identification of water sources for water use	Public participation in geographic information systems (GISs), OpenStreetMap (OSM)
	Biodiversity surveys	Species identification of invasive bumblebees and butterflies, coastal invasive species abundance, taxonomic identification
	Water consumption monitoring (e.g., reading water use meters, logging water-saving practices, and consumption patterns for residential and industrial uses)	Water diary, public engagement through telephone questionnaires
Food security	Urban agriculture monitoring (e.g., monitoring community gardens, rooftop gardens, and urban farms for crop yields, soil quality, and water usage)	Quantification of community garden crop yields
	Community food mapping (e.g., mapping food resources, food access points, assessment of food security and equity, promotion of food waste reduction, and sustainable agriculture)	Citizen science photovoice/diary food asset mapping
	Invasive species monitoring (quantitative measurements)	Volunteer-based assessment of invasive and native crab species in coastal states
	Monitoring pollination services	Pollinator monitoring mass participation citizen science, pollination service provision in gardens
	Water quality/quantity monitoring impacting food sources (e.g., freshwater/groundwater source for agriculture, shellfish habitats)	Visual observation (color, presence of algae, macrophytes, presence/absence of trash), quantitative measurements TDS green, pathogen and chemical pollutant monitoring
	Climate monitoring (e.g., air temperature, precipitation, humidity, cloud cover, measurement of CO_2 levels, cloud cover, sunshine duration)	CitizenSensing web application for climate profiles of cities submitted by citizens, rainfall monitoring
	Soil nutrient monitoring (e.g., soil pH, nitrogen, phosphorus, and potassium testing, organic matter content, cover crop studies, soil erosion assessment, microbial activity)	Visual Evaluation of Soil Structure (VESS) and extensive list of soil quality monitoring, Teabag Index for assessing soil biodiversity (soil biological activity), infiltration rate, quadrat-based visual assessment for vegetation cover
	Land use investigations (e.g., monitoring land use changes, biodiversity, seasonal phenology, assessment of historical land use, community mapping)	Land use change monitoring with citizen scientists

Table 2. *Cont.*

Societal Challenge [33]	NbS Success Metrics	CS Examples and Key Resources
Human health	Air quality monitoring (e.g., particulate matter, ground-level ozone)	Low-cost air quality measurement devices monitoring of tropospheric ozone
	Water quality monitoring	Visual observation (color, presence of algae, macrophytes, presence/absence of trash), quantitative measurements TDS green, pathogen and chemical pollutant monitoring
	Vector-borne disease monitoring (e.g., mosquito, tick, flea surveillance)	Vector identification and pathogen testing service for citizens—data used for vector population size estimation, monitoring of arboviral vectors across populations using participatory data
	Infectious disease surveillance	Collection of weekly health reports and survey data after influenza seasons
	Health behavior monitoring or surveillance (i.e., observation and recording of individual or population-level health-related actions and habits)	Monitoring health benefits of the natural environment as a CS program
	Noise pollution monitoring	Smartphone-based SPLnFTT sound meter application
	Food and nutrition monitoring	Dietary surveys, food diaries, nutritional studies monitoring dietary patterns, nutritional intake, and food-related behaviors
	Sanitation and hygiene (e.g., access to safe water and waste services)	Citizen science and nature-based sanitation solutions
Disaster risk management	Climate monitoring (e.g., air temperature, precipitation, humidity, cloud cover, measurement of CO_2 levels, cloud cover, sunshine duration)	Air and water temperature readings, rain gauge
	Flood monitoring	Flood risk-related data collection
	Community hazard mapping	Disaster risk reduction citizen science projects
	Wildfire monitoring, human fire behavior investigations	Smartphone-based Smoke Sense application to record smoke experiences, health symptoms, behaviors taken to reduce exposure to smoke.
	Volunteer geographic information (i.e., contribution of geospatial data such as maps, GPS tracks, geographic annotations to support disaster risk management activities)	Public participation in geographic information systems (GIS), OpenStreetMap (OSM)
	Seismic monitoring	Low-cost seismic sensors
Climate change	Climate monitoring (e.g., air temperature, precipitation, humidity, cloud cover, measurement of CO_2 levels, cloud cover, sunshine duration)	Air and water temperature readings, rain gauge
	Carbon footprint tracking (i.e., monitoring energy consumption, transportation habits, waste generation). Various online tools and mobile apps allowing individuals to calculate their carbon emission and opportunities to reduce their environmental impact.	CO_2 concentration living labs through I-Change program, carbon footprint, and energy content of food estimation using survey data
	Biodiversity monitoring (e.g., observing habitat changes due to climatic factors)	Visual/photo observations (birds, pollinators, mammals, amphibians and reptiles)
	Ocean monitoring (e.g., marine biodiversity surveys, coral reef monitoring, marine debris, fisheries tracking)	Observations for diversity, marine debris, geocaching with field notes, photos, and GPS data

Table 2. *Cont.*

Societal Challenge [33]	NbS Success Metrics	CS Examples and Key Resources
Climate change	Urban heat island monitoring	Distributed citizen-owned sensor network and mobile sensor deployment for publicly available infrastructure.
	Glacier monitoring (e.g., documenting changes in glacier size, mass, and dynamics through photography, GPS surveys, field observations)	Georeferenced glacier spot photos from tourist citizen scientists
	Remote sensing analysis	Visual classification of satellite imagery, community-based annotation of satellite imagery

Direct impacts to human health in the form of both psychological and physiological impacts [69], known impacts (e.g., stress and depression) and the mechanisms that modify these impacts, such as accessibility to NbS sites, nature views, or noise pollution, are expected to result in more direct impacts in the form of being able to take responsibility for these positive changes. "[CS] approaches may also have broader impacts, such as increasing science literacy and the likelihood that participants engage in pro-environmental activitie". [70].

While there are no conclusive trials, we demonstrate the availability of CS resources and techniques accessible through the internet and provide direction on a range of CS avenues to assess NbS success. The ease of access to participatory monitoring serves as a primary incentive for integrating CS into NbS planning and implementation, in addition to enhancing community connections and sense of place. CS enables local participants to bring into effect global changes and builds awareness and capacity to gradually address complex societal challenges [71]. Alternatively, examining the capacity of community participants based on access to training and material resources of the CS examples presented in Table 2 is one way to determine which technique applies for NbS initiatives that address societal challenges.

4. Conclusions

As nature-based solutions gain traction in government strategies for sustainable development, there will be a stronger reliance on CS to address the limitations of financial and human resources. The rise in environmental awareness and education is anticipated to further drive public motivation to embrace nature-based approaches. Here, we examined the current role of community in supporting the development and implementation of NbS and identified environmental monitoring as the gateway to advance NbS. We discerned a predominant focus on biodiversity monitoring, followed by water- and soil-related assessments. By prioritizing these monitoring efforts, stakeholders can glean vital insights into ecosystem health, track the effectiveness of interventions, and ensure the long-term sustainability of NbS. CS proves an invaluable step to supporting the multifunctionality of NbS.

The efficacy of NbS hinges upon the integration of CS methods at different stages of their implementation. From establishing baseline environmental parameters to engaging stakeholders in co-design processes, leveraging citizen science tools, monitoring infrastructure effectiveness, and fostering continuous community participation, these approaches collectively enhance the promotion, implementation, and assessment of NbS initiatives. By embracing these participatory methods, stakeholders can foster sustainable solutions that address societal challenges while promoting community engagement and empowerment in environmental conservation efforts.

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