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Research Trend of Citizen Science Themes 2019-2024: Systematic Literature Review

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ABSTRACT
Citizen Science has emerged as a popular and widely used approach in scientific research. This study analyses CS research through the lens of themes, research locations, and data analysis methods. A systematic literature review employing the PRISMA method was conducted, resulting in the analysis of 45 relevant articles retrieved from the Science Direct database. The results indicate that environmental pollution (31%) and conservation (24%) were the most prevalent project topics within CS research. Questionnaires emerged as the dominant data collection technique, while quantitative analysis methods were more frequently employed. Furthermore, the geographical distribution of CS research revealed a concentration in America and Europe. Notably, the application of CS research remains limited in Asia and Africa. An additional finding suggests a gap in research focusing on educational themes, particularly those exploring the involvement of educatorstudents, a local traditional leader in Citizen Science Project

Keywords: *citizen science; research trends; systematic literature review*

INTRODUCTION

Citizen Science (CS) has become a widely used and increasingly popular scientific approach. It involves the collaboration of volunteers and professional researchers to generate new scientific knowledge (Bonney et al., 2009). The value of CS in fostering a closer relationship between society and science by promoting deeper public engagement in issues concerning environmental risks and threats. In citizen science project (CSP), communities and stakeholders actively participate in research programs, such as data collection and large-scale surveys (Oturai et al., 2023). CSP encompass a wide range of topics, including reptile biodiversity identification (Wangyal et al., 2022a), plastic pollution (Heinimäki et al., 2021; Kiessling et al., 2021), aquatic vegetation identification (Webster et al., 2021), air pollution monitoring (Abhijith et al., 2024), drinking water pollution surveys (Redmon et al., 2020; Segev et al., 2021), building structure identification for disaster mitigation (Scaini et al., 2022), bat ecology observations (Greving et al., 2022), and coral reef monitoring (Meschini et al., 2021). These projects contribute significantly to improved environmental policies, benefiting stakeholders. Therefore, participants in CSP play a critical role by actively engaging in research. Beyond scientific contributions, CS fosters pro-environmental attitudes within society. It serves as a process that actively involves citizens in scientific development or alongside researchers, thus functioning as a bridge between scientists and the public (Thompson et al., 2023). With the growing disconnect between humans and nature (Soga & Gaston, 2016), CS offers an opportunity to reconnect with the natural world and contribute meaningfully. In conclusion, CS presents a valuable avenue for public participation in research, ultimately leading to environmental improvements.

CS has a long history of contributing to the advancement of natural science, which itself encompasses the study of both life science and physical science (Erduran et al., 2014). Key characteristics of natural science include observation of phenomena, hypothesis testing, and experimentation. One of the earliest examples is the meticulous recording of cherry blossoms blooming in Kyoto, Japan, dating back to 801 AD, by individuals like merchants, politicians, and monks (Aono & Kazui, 2008). Further historical accounts demonstrate the close connection between CS and natural science, as exemplified by the inherent curiosity and enthusiasm for understanding nature displayed by figures like explorers Alexander von Humboldt, Ferdinand Müller, and Maria Sibylla Merian (Vohland et al., 2021).

The past two decades have witnessed a surge in CSP, fueled by the advancement of internet technology. This has significantly enhanced project visibility, functionality, and accessibility (Scheibner et al., 2021). The online realm empowers individuals interested in diverse areas like fish observation, beetle research, environmental pollution monitoring, and educational initiatives to discover relevant CSP. Participants can readily access project instructions, actively contribute data directly to online databases (Phillips et al., 2019), and become integral parts of the scientific process. Furthermore, the internet has fostered the emergence of a new CS paradigm based on crowdsourcing (Bonney et al., 2009). Projects like *Galaxy Zoo* exemplify this approach, inviting the public to classify astronomical images captured by the Hubble Space Telescope (Raddick et al., 2019). As space exploration initiatives continue to generate vast datasets,CSP focused on data transcription, management, and interpretation are rapidly gaining traction. For instance, iNaturalist leverages smartphone applications to engage participants in documenting plant and animal species encountered in their natural habitats (Echeverria et al., 2021). This data serves as a valuable resource for scientists studying biodiversity patterns and species change over time. Similarly, *FrogWatch USA* mobilizes volunteers to monitor frog populations within their local backyards (Nemec et al., 2022). This data provides scientists with crucial insights into frog population health and the impact of factors like climate change.

Beyond direct data collection, CSP offers opportunities for public participation beyond fieldwork. Projects like *Riverkeeper Water Watch* in New York engage volunteers in water quality monitoring of rivers and streams by measuring parameters like temperature, pH, and dissolved oxygen levels (Forrest et al., 2019). This data empowers scientists to assess the health of waterways and identify potential pollution sources. Notably, CS encompasses both data collection and data analysis efforts. While some projects focus on field data collection, others harness the public's collective intellect to analyze vast datasets that would otherwise be unmanageable. In this way, the public plays a pivotal role in advancing scientific discovery.

The 21st century is characterized by complex and multifaceted global challenges, including climate change, biodiversity loss, and environmental pollution (Singh, 2021). CS emerges as an innovative approach to tackle these challenges by harnessing the collective power of the public. It allows individuals from diverse backgrounds and varying levels of expertise to participate actively in scientific research, thereby fostering greater inclusivity and diversity within the scientific community (Cooper et al., 2021; Roche et al., 2020). One crucial advantage of CS lies in its ability to address the limitations faced by scientists in collecting data, particularly for large-scale, long-term studies like those related to climate change (M. M. Haklay et al., 2021). By engaging a wider community in data collection, CSP can contribute to the generation of more comprehensive and geographically extensive datasets. However, it is crucial to acknowledge that data collected by the public may exhibit variability in accuracy and consistency. Therefore, the role of scientists remains essential in validating and ensuring the integrity of the data, thereby mitigating potential biases in interpretation (Bowser et al., 2020). This collaborative effort fosters a mutually beneficial relationship, enabling the public to gain valuable insights from scientific data and utilize it for informed decision-making at the community level.

CS also holds significant promise in supporting the achievement of the Sustainable Development Goals (SDGs) established by the United Nations in 2015. These 17 interconnected goals, encompassing areas like health, education, environment, and social justice, aim to eliminate global challenges such as poverty, hunger, and inequality (UNRP, 2015). CSP can contribute to this agenda by collecting and monitoring crucial environmental, social, and health data, complementing and strengthening the efforts of government agencies and research organizations (Chapman & Hodges, 2017). Examples include monitoring water quality (Redmon et al., 2020), tracking invasive species (Colombari & Battisti, 2023), monitoring coastlines (Harley & Kinsela, 2022), and assessing plastic waste pollution (Clark et al., 2023). Furthermore, CSP play a vital role in raising public awareness about the SDGs and educating the public on the importance of sustainable development. The data and information obtained through these projects can then inform evidence-based policymaking, allowing policymakers to create targeted and effective interventions aimed at achieving the SDGs (Criscuolo et al., 2023). In conclusion, CS presents a powerful tool for addressing global challenges and achieving sustainable development in the 21st century. By fostering public participation in scientific research, facilitating data collection, and raising awareness about critical issues, CS paves the way for a more inclusive, collaborative, and informed approach to tackling the complex problems facing our planet.

CS has demonstrably been and will continue to be, critical to the advancement of the natural sciences (Bonney et al., 2009). Sharing a core objective – unearthing the mysteries of the natural world – CS and natural science operate in a mutually beneficial synergy. This shared mission motivates volunteers to dedicate their time and effort to a diverse array of crowdsourcing initiatives that leverage citizen contributions through large-scale observations (Haklay et al., 2021). The societal contribution to the evolution of the natural sciences is well-documented (Cooper et al., 2021). Current classifications of CSP recognize them as approaches holding significant promise for the future of scientific exploration. Examples abound, offering communities the opportunity to employ scientific methods to quantify the severity and distribution of air pollution, thereby facilitating environmental justice initiatives (Fogg-Rogers et al., 2024). Similarly, CS empowers communities to engage in sustainable water management practices (Pandeya et al., 2021) and contribute to the monitoring of endangered species (Lloyd et al., 2020). Expanding opportunities for citizen involvement throughout various stages of scientific discovery promises to enhance public scientific literacy (Brandt et al., 2022). When meticulously planned, a vibrant CS community can provide holistic insights into the critical challenges confronting our world in the 21st century.

A significant segment of CSP focused on biodiversity aims to map species distribution and quantify their populations. Data collected through such projects (e.g., *eBird , iNaturalist, iSpot*) informs various studies, enabling researchers to track population trends and map species ranges. The accelerated pace of global change necessitates a corresponding expansion of CS across various sectors (Haklay et al., 2021). Beyond biodiversity, CS holds significant potential for data collection on a broad spectrum of issues, including ecological monitoring, pollution distribution, and risk factor identification. The diverse applications of CS across multiple fields serve as a powerful testament to society's immense capacity to contribute meaningfully to scientific research. Through active community participation, CS can offer solutions to various challenges and ultimately improve the quality of human life. This research aims to explore thematic areas and evaluate the implementation of previously executed CSP.

METHODOLOGY

A systematic search was conducted using the ScienceDirect database, which yielded a total of 667 articles and other database 11 articles published between 2019 and 2024. To ensure comprehensive coverage, a combination of keywords was utilized: "citizen science," "citizen science project", "participatory science," "crowdsourcing," and "participatory community science." Additionally, the search was limited to articles within the focus areas of social sciences, agriculture & biological sciences, and environmental science. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework was adopted to guide the article selection process. This process involved three key stages such as identification, screening, eligibility,and including. Relevant keywords were identified by consulting prior research, thesauri, and expert recommendations. This initial search yielded a total of 393 articles. Based on established inclusion and exclusion criteria detailed in Table 2, a total of 174 articles were deemed eligible for further review. These criteria pertained to the type of literature (journals), language (English), and field of study (agricultural & biological sciences, environmental science, and social sciences). Full-text access was obtained for the 174 potentially relevant articles. Following a rigorous review process informed by inclusion and exclusion criteria, 45 articles were identified as suitable for further in-depth analysis (Table 1.).

Table 1. Inclusion and Exclusion Criteria

Criteria	Eligibility	Exclusion
Time	Articles published in at least 2019	< 2019
Language	English	Discuss other than English
Paper type	Journal article	Proceedings articles, reviews, books, book series
Fields in the database *ScienceDirect*	Agricultural, biological science, environmental science, social science (biology education, physics education, chemistry education, science education	Medicine, dentistry, business, economics, psychology, energy, art&humanities

RESULT AND DISCUSSION

This section presents the analysis of the 34 selected articles, focusing on themes, participant characteristics, duration, and project outcomes (summarized in Table 2).

Dominant Theme in CS Projects

Environmental pollution and conservation emerged as the dominant themes among the analyzed CSP, accounting for 55% of projects (Figure 2). Environmental pollution projects (31%) collect data on various aspects, including: air quality monitoring through lichen observation (Counoy et al., 2023), identification of river pollution caused by agricultural pesticides (von Gönner et al., 2023), monitoring coastal microplastic pollution (Jones et al., 2022a). Then, conservation projects (24%) focus on monitoring diverse species: pollinator bee diversity (Mason & Arathi, 2019), bats in urban areas (Greving et al., 2022), angel sharks in the Mediterranean Sea (Giovos et al., 2019). Additional project themes are ecological observation and education projects represent 11% of the reviewed CSP. Examples include amphibian monitoring in North America (Estes-Zumpf et al., 2022), reptile and amphibian monitoring in Bhutan (Wangyal et al., 2022b), aquatic vegetation identification in Chesapeake Bay (Webster et al., 2021). Education sector contributes 13% of CSP, encompassing projects like enhancing computer literacy through facilitator organizations (Smith et al., 2023), investigating classroom environment's impact on student focus (Toftum & Clausen, 2023), fostering environmental learning through online communities (Herodotou et al., 2022). The agricultural sector represents 4% of projects, focusing on identifying organisms beneficial to agricultural land (Billaud et al., 2021), flower biodiversity assessment (Bedessem et al., 2022) While remaining at 2%, CSPs also cover diverse fields like nanotechnology, hydrology, disaster mitigation, biological invasion, marine, and forestry, demonstrating the broad applicability of CSP.

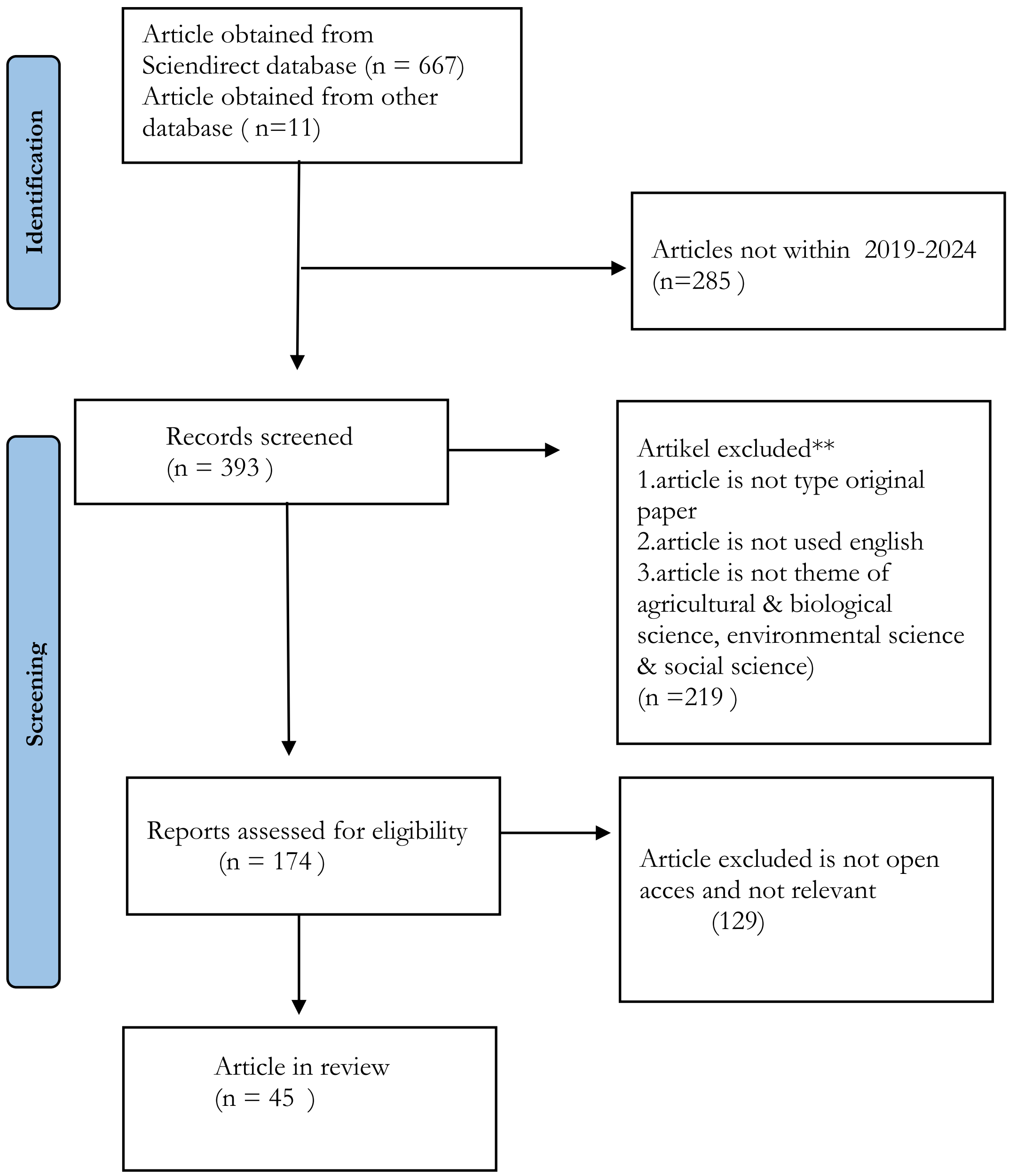


Figure 1. Selection and Extraction of data for SLR

Environmental pollution poses a significant threat to our planet, with specific concerns surrounding waste pollution's detrimental impact on aquatic ecosystems and the wider environment. Studies have highlighted the transportation of vast amounts of plastic waste from rivers to the ocean (McCormick & Hoellein, 2016; Meijer et al., 2021; Vigneswaran et al., 2022), contributing to environmental, economic, and social challenges. Estimates suggest that annually, 2.8 million tons of plastic waste enter the sea through rivers, highlighting the critical need for effective waste management (Schmidt et al., 2017). Recent research further underscores the widespread impact of anthropogenic waste on wildlife, such as the consumption of microplastics by freshwater fish (Li et al., 2021) and the incorporation of plastic into bird nests (Votier et al., 2011). Additionally, consuming water contaminated with microplastics poses a potential health risk to humans.

Public interest in monitoring water and air pollution is on the rise. This translates to increased community participation in hydrological studies, encompassing data collection related to both water quantity and quality (Buytaert et al., 2014; Njue et al., 2019). The multifaceted objectives of community-based water quality monitoring projects lead to diverse approaches, involving variations in focus, methodologies employed, and sampling frequency. Similarly, communities are increasingly involved in air quality monitoring, often utilizing bioindicators such as lichens (Counoy et al., 2023). Project durations vary, with some campaigns spanning multiple years, while others operate for several months (Jones et al., 2022a; Kiessling et al., 2021; von Gönner et al., 2023; Wichmann et al., 2022). The methods chosen for collecting water and air quality data depend on several factors like the specific pollutants or characteristics being measured; volunteer availability; the number of volunteers participating in data collection; project budget and duration, financial resources, and the timeframe allocated to the project. These factors, in turn, influence the spatial and temporal resolution of the collected data, ultimately impacting its value for various hydrological studies. For example, one-time sampling events often involve large volunteer groups and utilize cost-effective methods. While this approach offers broader spatial coverage, the resulting data may have lower precision (McKinley et al., 2017). This trade-off between scale and accuracy represents one of the key challenges and limitations inherent in CSP projects.

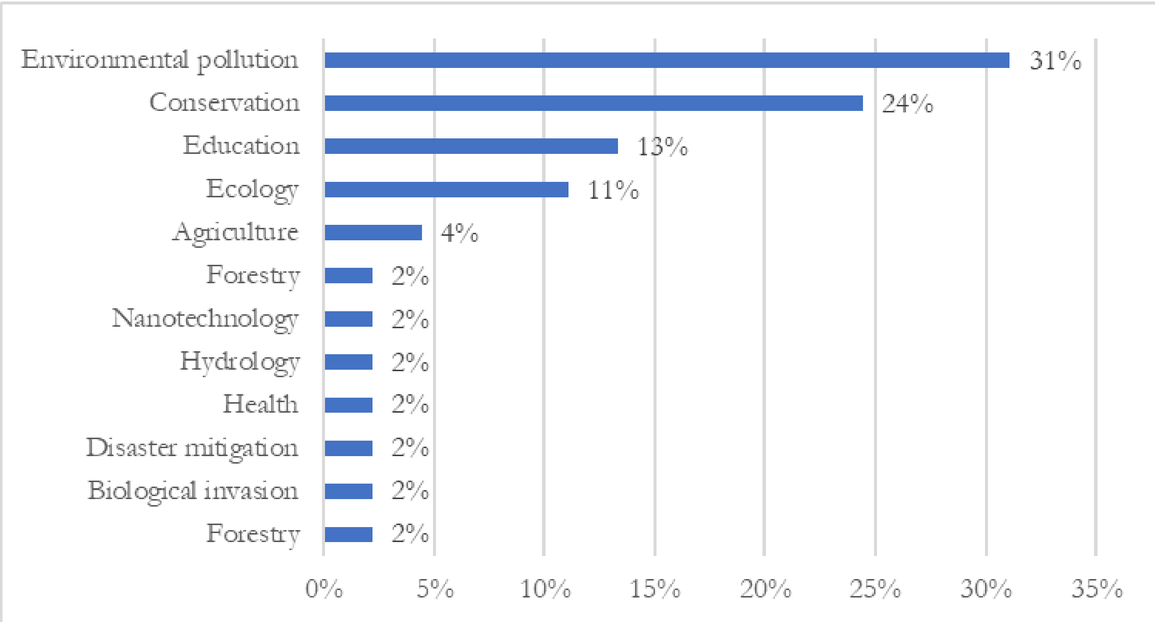


Figure 2. Popular theme of CSP

CS offers a compelling solution to overcome large-scale conservation challenges by leveraging its inherent broad reach and community involvement. Community engagement, including students, can be better at helping with decision-making (Gusti et al., 2024). This fosters better-informed decision-making on conservation policies and outcomes. Similar to conventional research, CS strategies employed for conservation advancements involve acquiring scientific knowledge (McKinley et al., 2017). Volunteers play a crucial role in generating valuable scientific information that aids conservation scientists, natural resource and environmental managers, and policymakers. CS influences decision-making and fuels community engagement in managing and formulating policies related to natural resources and the environment (Hyder et al., 2015). CS facilitates direct and indirect input from volunteers into decision-making processes. For instance, volunteers can use their acquired knowledge from CSP to comment on proposed government actions. Additionally, their involvement can be indirect, such as sharing information within their communities and inspiring others to engage in conservation efforts, natural resource management, and environmental protection (Ellwood et al., 2017).

Table 2. Analysis of Selected Studies

No	Author	CSP theme	CSP Topics	CSP Team	Number involved	Duration
1	(Hsu et al., 2019)	Conservation	Crab Conservation	Volunteer (20-30 years)	30	6 hours
2	(Billaud & Porcher, 2021)	Agriculture	Identify organisms in agricultural land (bees, worms, mollusks, butterflies	Researchers and farmers	1216	7 years
3	(Meschini et al., 2021)	Conservation	Coral reef conservation	Researcher and Volunteer	212	3 years
4	(Bedessem et al., 2022)	agriculture	flower identification	general public	1404	2 elastics
5	(Fernández-Álvarez & Gutiérrez Ladrón de Guevara, 2022)	Forestry	Observation of forest use	general public	26609	2 years
6	(Counoy et al., 2023)	environmental pollution	air quality monitoring	Researchers and the general public	25	3 years
7	(by Gönner et al., 2023)	environmental pollution	monitoring river water quality	Researcher and Volunteer	303	4 months
8	(Giovos et al., 2019)	Conservation	Identify angel sharks	Researchers and Volunteers (Fishermen, Divers, fish sellers)	3000	4 months
9	(Colombari & Battisti, 2023)	Biological Invasion	Identify the ambrosia beetle	Researchers, teachers and students	500	1 month
10	(Wichmann et al., 2022)	environmental pollution	identification of marine waste pollution	Researchers, teachers and students	756	4 months
11	(Greving et al., 2022)	Conservation	Ecological observations of bats	Researchers and Volunteers (doctoral students, general public)	139	1.5 years
12	(Smith et al., 2023)	Education	Computer learning	Schools, Entrepreneurs, NGOs	231	2.5 years
13	(Toftum & Clausen, 2023)	Education	The influence of the classroom environment on students	government and schools	4364	2 weeks
14	(Scaini et al., 2022)	Disaster mitigation	identification of building structures as earthquake disaster mitigation	school	170	3 months
15	(Gell et al., 2023)	Food	Identify healthy foods at school	School	25	unexplained

No	Author	CSP theme	CSP Topics	CSP Team	Number involved	Duration
16	(Pandeya et al., 2021)	Hydrology	Water management	researchers, Department of Hydrology and Meteorology, local government, local NGOs, and local government authorities, local communities	unexplained	unexplained
17	(Estes-Zumpf et al., 2022)	Ecology	Ecological monitoring of amphibians	researchers, biologists and volunteers	328	4 months
18	(Wangyal et al., 2022a)	Ecology	Identify reptiles and amphibians	researcher, biologist, volunteer (Boy Scout Troop, Rocky Mountain Youth Corps, Wyoming Conservation Corps, discovery camp, church group)	235	5.5 years
19	(Potsikas et al., 2023)	Conservation	Identify biodiversity in lakes	researchers, students, the general public	116	1 week
20	(Herodotou et al., 2022)	Education	Environmental education	community (young people 11-19 years)	34	unexplained
21	(Joubert et al., 2020)	Nanotechnology	Survey of knowledge and attitudes towards nanotechnology	community (aged 11-87 years)	1067	17 months
22	(Jones et al., 2022b)	Environmental pollution	identification of microplastics on beaches	volunteers (high school and university students)	50	10 months
23	(Mason & Arathi, 2019)	Conservation	Monitoring bee pollinator diversity	researchers, laboratory analysts and volunteers	30	1 year
24	(Kiessling et al., 2021)	environmental pollution	identification of river pollution	volunteers (students and youth organizations)	5500	8 months
25	(Webster et al., 2021)	Ecology	Identification of submerged aquatic vegetation	researcher, expert (biology and water management), volunteer	60	2.5 years
26	(Redmon et al., 2020)	environmental pollution	identification of drinking water contamination	researchers, kindergarten teachers and laboratory analysts	86	5 months
27	(Fogg-rogers et al., 2024)	environmental pollution	survey of involvement in policy making regarding air pollution	researchers and volunteers (aged 16-24 years)	857	unexplained
28	(Segev et al., 2021)	environmental pollution	identify contamination of drinking water sources	researchers and volunteers (local community)	652	4 months

No	Author	CSP theme	CSP Topics	CSP Team	Number involved	Duration
29	(Cardoso-Andrade et al., 2022)	environment	coastal environmental monitoring	researchers and volunteers (aged 24-38 years)	345	unexplained
30	(Abhijith et al., 2024)	environmental pollution	air pollution monitoring	researchers and volunteers	119	4 months
31	(Clark et al., 2023)	environmental pollution	Identify plastic waste in rivers	researchers and volunteers	84	1 year 8 months
32	(Lloyd et al., 2020)	Conservation	monitoring endangered species	researchers and volunteers	unexplained	8 months
33	(Harley & Kinsela, 2022)	Marine	monitoring shoreline changes	researchers and volunteers	198	7 months
34	(Maharani et al., 2022)	Conservation	Amphibian monitoring	volunteer	unexplained	3 years
35	(Cabrini et al., 2021)	environmental pollution	Air pollution	researchers and volunteers	2715	unexplained
36	(Shaw et al., 2023)	environmental pollution	Identify metaloid substance from honey	researchers and volunteers	263	1 year
37	(Pernat et al., 2023)	Conservation	Monitoring plant biodiversity	researchers and volunteers	20	6 month
38	(Loiselle et al., 2024)	environmental pollution	Monitoring of water pollution in river	researchers and volunteers	1800	2 month
39	(von Gönner et al., 2024)	environmental pollution	Monitoring of water pollution in river	researchers and volunteers	96	3 years
40	(Garretson et al., 2023)	Conservation	Insecta monitoring	researchers and volunteers	11224	unexplained
41	(Chitimia-Dobler et al., 2024)(Pernat et al., 2023)	Conservation	Monitoring of Hyalomma ecology	researchers and volunteers	unexplained	3 years
42	(Muaziyah et al., 2023)	Education	Weather monitoring	researchers , teachers, students	32	1month
43	(Aripin et al., 2021b)	Education	Conservation in Biology learning	researchers ,lecturer, students	111	6 month
44	(Aripin et al., 2021c)	Conservation	Indentify of Mango insecta	researchers ,lecturer, students	68	4 month
45	(Rachmawati et al., 2022)	Education	Biodiversity learning	researchrs ,lecturer, students	104	unexplained

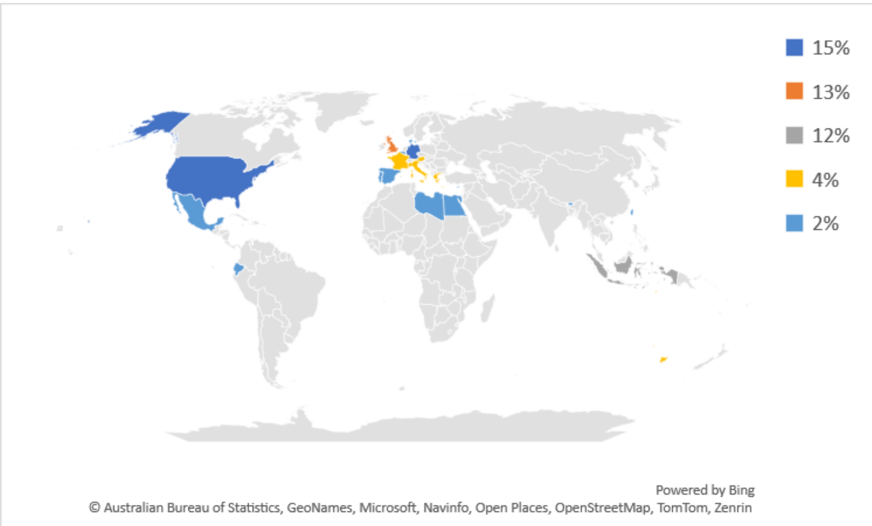
CSP can be implemented in the field of education to involve both students and educators. The implementation of this project is related to the demands of learning (Damayanti et al., 2021). Aripin et al. (2022) implemented a CSP on insect biodiversity using research guidelines to ensure a systematic learning process. Susbiyanto et al. (2024) developed instruments for ecology education based on CS. Citizen participation contributes to the achievement of science learning goals, including interest in science and the environment, self-efficacy, motivation to learn science, and knowledge of nature (science process) and the environment (Aripin et al., 2021a, 2023). However, many students do not yet understand the meaning of CSP (Gusti et al., 2024).

In the face of large-scale and complex environmental challenges, CSP presents powerful solutions for the fields of conservation biology, natural resource management, and environmental protection. The rapidly changing nature of our planet's biological and physical systems, driven by expanding human activities, poses significant threats (Didenko et al., 2017; Kummer & Turner, 1994). Environmental damage caused by factors like urbanization, deforestation, and land-use conversion for agriculture jeopardizes the survival of numerous species. CSP plays a pivotal role in environmental improvement by contributing to building scientific knowledge; Providing valuable input for policy formulation; and inspiring community action By harnessing the collective power of CSP, communities can actively participate in addressing the critical conservation challenges we face today.

Distribution of CSP locations in the last five years

CS has witnessed rapid growth across various nations worldwide, fueled by a confluence of factors: technological advancements, heightened public awareness, and a growing need for data (Follett & Strezov, 2015; Newman et al., 2012). The internet and other communication technologies have facilitated public participation in scientific research, while the public itself demonstrates an increasing desire to contribute to scientific endeavors. Additionally, scientists require more data to address complex issues, and CS offers a valuable avenue for data collection. Beyond data collection, CS allows for the refinement of research questions. Project participants, immersed in their local environments and natural resources, can contribute valuable insights that enhance the relevance and local applicability of research questions, ultimately benefitting both scientists and local communities (Herodotou et al., 2022).

Recent years have seen a burgeoning of CSP initiatives across multiple countries. Notably, conservation efforts have been at the forefront of these projects. Prominent examples include large-scale initiatives in the United States (https://participatorysciences.org), Europe (https://www.ecsa.ngo), and Australia (https://citizenscience.org.au). This growth is driven by the recognition of the potential that CS holds by government agencies, universities, and national/international organizations. Consequently, new organizations dedicated to CS-based research, often with conservation goals, have emerged (Ellwood et al., 2017).



Countries	Percentage
United States	15%
Germany	15%
United Kingdom	13%
Indonesia	12%
Italy	4%
Australia	4%
Greece	4%
Austria	4%
France	4%
Taiwan	2%
Portugal	2%
Spain	2%
Ecuador	2%
Bhutan	2%
Denmark	2%
Libya	2%
Cyprus	2%
Belgium	2%
Mexiko	2%
Egypt	2%

Figure 3. CSP distribution across countries 2019-2024

Figure 3 provides a snapshot of CSP distribution across various countries. While the United States and Germany remains the largest contributor with 15%, significant participation is also observed in several European nations: United Kingdom (13%), Indonesia (12%), Italy (4%), Australia, Greece, Austria and France also demonstrates notable engagement (4%). While CSP in Asia and Africa remains less prevalent, with recent projects identified in Taiwan and Bhutan (2%), and Egypt, Libya (2%), the spread of this collaborative approach has demonstrably reached these continents.

While parallels are often drawn between early scientific endeavors and today's public involvement , the scale and depth of modern engagement surpass previous forms of participation. This holds even in areas like astronomy and ecological observation, where changes in participant skill sets and knowledge are evident (Haklay, 2015). Europe stands out as a global leader in CS development, driven by factors common to other regions, alongside unique strengths like Government support, High-quality human resources, and Diverse environmental challenges. Wagenknecht et al. (2021), highlight the role of government funding in fostering CS programs. Haklay (2015) emphasizes the importance of a skilled workforce for successful CS initiatives. Cardoso et al. (2017) point out the unique environmental issues. Europe faces, which necessitate citizen involvement. Several European nations, including Germany, England, and the Netherlands, exemplify this leadership by providing financial and infrastructural support for CS programs. Notably, Europe has a strong tradition of scientific research, which fosters collaboration between academia and society.

The global expansion of higher education is another significant factor influencing CS potential. Developed countries, for instance, have witnessed a dramatic increase in tertiary education attainment (Haklay, 2015). The UK saw a rise from 1.6% of the population holding a tertiary degree in 1950 to 21.7% in 2010. This trend, observed across developed nations, suggests a growing societal orientation towards scientific thinking, creating a fertile ground for CS engagement.

CSP remains underutilized as a tool for sustainable development, particularly in Asia and Africa (Cardoso et al., 2017). However, emerging projects showcase the possibilities. In Taiwan, A collaborative effort by regional educational and park authorities launched a CS project in 2017 focused on land crab protection (Hsu et al., 2019). The project involves assisting crab migration during breeding season, monitoring species populations, collecting ecological data, and promoting environmental education. In Bhutan, Wangyal et al. (2022a) highlight the exceptional opportunity for CSP to reveal amphibian and reptile distribution in Bhutan. This opportunity stems from the country's high forest cover, low human population density, and minimal environmental degradation compared to neighboring regions. Therefore, CSP holds significant potential for both biodiversity exploration and potential species discovery. Aripin et al. (2022) demonstrate the application of CSP within the context of Indonesian mango plantations. These examples demonstrate the growing potential and diverse applications of CSP in Asia and Africa. As CS continues to evolve, it holds immense promise for advancing scientific research, promoting environmental stewardship, and fostering collaborative solutions to global challenges across all continents.

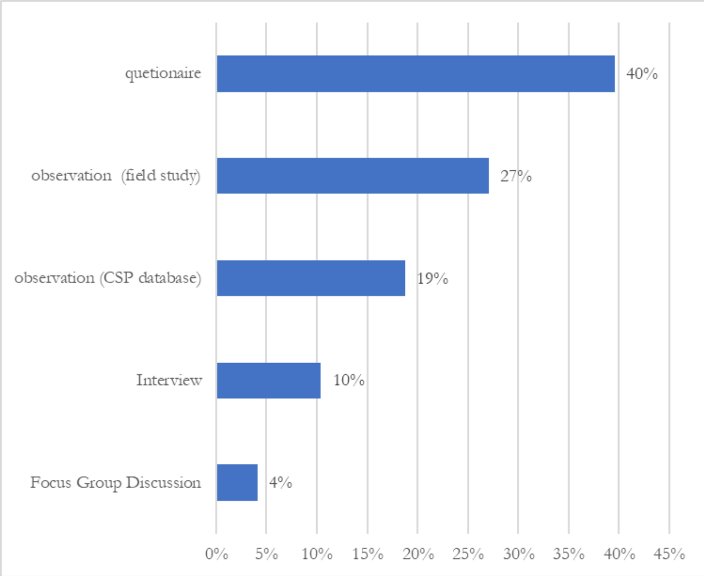


Figure 4. Popular data collection methods in CS research

CS empowers the community to collaboratively collect valuable data through various methods. This data and the resulting information become valuable resources for scientists, decision-makers, and the public alike. One key method of public contribution is crowdsourcing, where a large number of individuals participate in data processing and analysis. CSP can utilize diverse data collection instruments, including questionnaires, observation sheets, interviews, and secondary data collection. These structured surveys gather quantitative data from participants, as exemplified by Hsu et al. (2019) who measured environmental literacy levels. These standardized forms record specific observations, allowing for standardized data collection across participants. In-depth interviews gather qualitative data and deeper insights, as seen in Colombari & Battisti's (2023) study measuring participant understanding of biological threats. Existing data from databases can be repurposed for CSP enriching the overall data pool.

Data collection methods in CSP facilitate public participation and empower citizens to contribute to research. The predominant approach is utilizing questionnaires (40%) to gauge participant understanding, perceptions, and attitudes (Rameshbhai Patel & Joseph, 2016). These structured surveys gather quantitative data through written questions designed to elicit specific information and opinions. Observation methods also play a significant role, with field observation (27%) and data observation from project databases (19%) being common examples. *eBird* (https://*eBird* .org/home), launched in 2002, exemplifies this approach. This program, a collaboration between the Cornell Lab of Ornithology and the National Audubon Society, engages a vast network of citizen scientists who report bird sightings using standardized protocols. *eBird* aims to leverage the collective power of everyday birdwatchers to gain a deeper understanding of bird distribution and abundance across diverse spatial and temporal scales (Rameshbhai Patel & Joseph, 2016). Similarly, the French CSP *Farmland Biodiversity Observatorium* (FBO), launched in 2011, involves 1,216 farmers monitoring biodiversity on their farms (Billaud et al., 2021). This project ensures a comprehensive representation of agricultural practices and crop distribution across France.

The late 20th and early 21st centuries witnessed a technological revolution that significantly impacted data collection in CSP. This revolution enabled the capture of diverse data types, including images, video, and sound, which support and facilitate the exploration of new research questions (Johnson et al., 2020). Technological advancements have also fostered the development of networks that enable data sharing through the Internet, creating globally accessible datasets (Aristeidou & Herodotou, 2020). For effective CSP, technological tools must be accessible, usable, and useful. Fortunately, recent advancements have addressed these aspects: accessibility, usability, and usefulness. Hardware costs have gradually decreased, improving access to technology for wider participation. Advancements in design and sensors have led to more user-friendly and intuitive tools. Modern sensors, like digital cameras, audio recorders, GPS devices, drones, and eDNA sampling kits, empower volunteers to collect vast amounts of data in the field.

Mobile phones have emerged as powerful tools for CSP, driven by their widespread adoption and ability to capture and transmit data efficiently (Aristeidou et al., 2021; Longo et al., 2020). This technology facilitates local participatory monitoring, such as the *EpiCollect* platform (Dunbar-Wallis et al., 2021), and global CS initiatives, exemplified by *eBird* (Sullivan et al., 2009). However, unequal access to mobile technology presents a challenge. Studies like Beza et al. (2017) highlight this disparity; while over 90% of surveyed farmers across India, Honduras, and Ethiopia owned phones, less than 60% had consistent network connectivity and even fewer (<10%) used mobile internet. This disparity extends to smartphone ownership, which varies significantly between developed and developing countries (Silver, 2019). While developed nations like South Korea boast high ownership rates (95%), others like India, Kenya, and Nigeria (24%-41%). These disparities are further exacerbated by variations within countries based on factors like network access, income, education, and location (rural vs. urban). Despite these challenges, the untapped potential exists in regions like Bhutan, where most individuals carry internet-connected phones with cameras and actively share wildlife photos on social media (Wangyal et al., 2022b). This highlights the potential of CS in generating data for understudied taxonomic groups like reptiles and amphibians.

Technological advancement plays a crucial role in enhancing community participation by providing accessible online tools. The information technology revolution, with the rise of the internet and mobile technology equipped with location features, cameras, and sensors, has significantly expanded the capabilities and impact of CS (Toerpe, 2013). Platforms like social media (e.g., Facebook, Twitter) serve as valuable tools for organizing, monitoring support, and facilitating knowledge sharing among participants. For instance, the Garden Bioblitz in England (https://www.parksconservancy.org/events/mount-tamalpais/fungi-and-friends-bioblitz) utilizes social media to establish new projects and foster collaboration. This ability to access, store, manage, analyze, and share data on a large scale underlines the potential of technology to further enhance CSP endeavors.

CONCLUSION

CSP is experiencing a surge in interest, with environmental pollution and conservation emerging as prominent research themes. Within the pollution domain, water and air quality monitoring appear to be the most popular topics. Conservation efforts often prioritize animal conservation. Quantitative data collection techniques are currently predominant in CS projects. However, a gap exists in integrating CSP into formal education and actively engaging local communities, particularly traditional stakeholders. CSP can be incorporated into higher education curricula, fostering student engagement in scientific inquiry and environmental issues. Collaboration with local traditional leaders can promote the inclusion of local knowledge and perspectives in CSP, leading to more holistic and culturally sensitive research strategies. By bridging these gaps, CSP can become a powerful tool for environmental stewardship, fostering scientific literacy, and empowering local communities to actively participate in shaping sustainable solutions.

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REFERENCES

Abhijith, K. V., Kumar, P., Omidvarborna, H., Emygdio, A. P. M., McCallan, B., & Carpenter-Lomax, D. (2024). Improving air pollution awareness of the general public through citizen science approach. *Sustainable Horizons*, *10*(January), 100086. https://doi.org/10.1016/j.horiz.2023.100086

Aono, Y., & Kazui, K. (2008). Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *28*(7), 905–914.

Aripin, I., Hidayat, T., Rustaman, N., & Riandi. (2022a). *Panduan Dasar Riset Biodiversitas Berbasis Citizen Science Project*. Perkumpulan Rumah Cemerlang Indonesia. https://edeposit.perpusnas.go.id/collection/panduan-dasar-riset-biodiversitas-berbasis-citizen-science-project-sumber-elektronis/105960#

Aripin, I., Hidayat, T., Rustaman, N., & Riandi. (2023). Kontribusi Citizen Science Project Terhadap Capaian Pembelajaran Sains: Sistematik Literatur Review. *Edusains*, *15*(August), 5–24.

Aripin, I., Hidayat, T., Rustaman, N., & Riandi, R. (2021a). Pengembangan Program Perkuliahan Biologi Konservasi Berbasis Citizen Science Project. *Pedagogi Hayati*, *5*(1), 1–9.

Aripin, I., Hidayat, T., Rustaman, N., & Riandi, R. (2022b). Citizen science project's contributions to species literacy for pre-service biology teacher. *Jurnal Bioedukatika*, *10*(1), 42. https://doi.org/10.26555/bioedukatika.v10i1.21646

Aripin, I., Hidayat, T., Rustaman, N., & Riandi, R. (2022c). Monitoring mango (Mangifera indica) pollinator: Evaluate learning outcome for the participating citizen science. *AIP Conference Proceedings*, *2468*(1).

Aripin, I., Hidayat, T., Rustaman, N. Y., & Riandi, R. (2021b). Monitoring of insect pollinators of mango (Mangifera indica L.) inflorescence based on citizen science. *Biogenesis: Jurnal Ilmiah Biologi*, *9*(2), 156. https://doi.org/10.24252/bio.v9i2.23509

Aristeidou, M., & Herodotou, C. (2020). Online citizen science: A systematic review of effects on learning and scientific literacy. *Citizen Science: Theory and Practice*, *5*(1), 1–12.

Aristeidou, M., Herodotou, C., Ballard, H. L., Higgins, L., Johnson, R. F., Miller, A. E., Young, A. N., & Robinson, L. D. (2021). How do young community and citizen science volunteers support scientific research on biodiversity? The case of inaturalist. *Diversity*, *13*(7). https://doi.org/10.3390/d13070318

Bedessem, B., Torres, A. C., Fontaine, C., & Deguines, N. (2022). Science learning in biodiversity citizen science: Inputs from the analysis of online social interactions within a contributory project for pollinators' monitoring. *Biological Conservation*, *276*(October), 109807. https://doi.org/10.1016/j.biocon.2022.109807

Beza, E., Steinke, J., van Etten, J., Reidsma, P., Fadda, C., Mittra, S., Mathur, P., & Kooistra, L. (2017). What are the prospects for citizen science in agriculture? Evidence from three continents on motivation and mobile telephone use of resource-poor farmers. *PLOS ONE*, *12*(5), e0175700. https://doi.org/10.1371/journal.pone.0175700

Billaud, O., & Porcher, R. V. E. (2021). *Citizen science involving farmers as a means to document temporal trends in farmland biodiversity and relate them to agricultural practices*. *January 2020*, 261–273. https://doi.org/10.1111/1365-2664.13746

Billaud, O., Vermeersch, R. L., & Porcher, E. (2021). Citizen science involving farmers as a means to document temporal trends in farmland biodiversity and relate them to agricultural practices. *Journal of Applied Ecology*, *58*(2), 261–273. https://doi.org/10.1111/1365-2664.13746

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioscienceBioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bowser, A., Cooper, C., De Sherbinin, A., Wiggins, A., Brenton, P., Chuang, T.-R., Faustman, E., Haklay, M., & Meloche, M. (2020). Still in need of norms: the state of the data in citizen science. *Citizen Science: Theory and Practice*, *5*(1).

Brandt, M., Groom, Q., Magro, A., Misevic, D., Narraway, C. L., Bruckermann, T., Beniermann, A., Børsen, T., González, J., & Meeus, S. (2022). Promoting scientific literacy in evolution through citizen science. *Proceedings of the Royal Society B*, *289*(1980), 20221077.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., De Bièvre, B., Bhusal, J., Clark, J., & Dewulf, A. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*, *2*, 26.

Cabrini, F., Cavallo, C., & Scalenghe, R. (2021). An Early Beginning of Citizen Science: Adolescents Experiencing Urban Energy Usages and Air Pollution. *Adolescents*, *1*(3), 225–251. https://doi.org/10.3390/adolescents1030018

Cardoso-Andrade, M., Cruz-Jesus, F., Souza Troncoso, J., Queiroga, H., & M. S. Gonçalves, J. (2022). Understanding technological, cultural, and environmental motivators explaining the adoption of citizen science apps for coastal environment monitoring. *Global Environmental Change*, *77*(January), 102606. https://doi.org/10.1016/j.gloenvcha.2022.102606

Cardoso, A. C., Tsiamis, K., Gervasini, E., Schade, S., Taucer, F., Adriaens, T., Copas, K., Flevaris, S., Galiay, P., & Jennings, E. (2017). Citizen science and open data: A model for invasive alien species in Europe. *Research Ideas and Outcomes*, *3*, e14811.

Chapman, C., & Hodges, C. (2017). Can Citizen Science Seriously Contribute to Policy Development?: A Decision Maker's View. In *Analyzing the Role of Citizen Science in Modern Research* (pp. 246–261). IGI Global.

Chitimia-Dobler, L., Springer, A., Lang, D., Lindau, A., Fachet, K., Dobler, G., Nijhof, A. M., Strube, C., & Mackenstedt, U. (2024). Molting incidents of Hyalomma spp. carrying human pathogens in Germany under different weather conditions. *Parasites and Vectors*, *17*(1), 1–10. https://doi.org/10.1186/s13071-024-06175-y

Clark, L., Allen, R., Botterell, Z. L. R., Callejo, B., Godley, B. J., Henry, C., Santillo, D., & Nelms,

S. E. (2023). Using citizen science to understand floating plastic debris distribution and abundance: A case study from the North Cornish coast (United Kingdom). *Marine Pollution Bulletin*, *194*(PB), 115314. https://doi.org/10.1016/j.marpolbul.2023.115314

Colombari, F., & Battisti, A. (2023). Citizen science at school increases awareness of biological invasions and contributes to the detection of exotic ambrosia beetles. *NeoBiota*, *84*, 211–229. https://doi.org/10.3897/NEOBIOTA.84.95177

Cooper, C. B., Hawn, C. L., Larson, L. R., Parrish, J. K., Bowser, G., Cavalier, D., Dunn, R. R., Haklay, M., Gupta, K. K., & Jelks, N. O. (2021). Inclusion in citizen science: The conundrum of rebranding. *Science*, *372*(6549), 1386–1388.

Counoy, H., Turcati, L., Lorrillière, R., Bénateau, S., Maalouf, J. P., Agnello, G., Turpin, S., & Agnan, Y. (2023). Performance evaluation and applicability of Lichens GO, a citizen science-based protocol for urban air quality monitoring. *Ecological Indicators*, *150*(October 2022). https://doi.org/10.1016/j.ecolind.2023.110269

Criscuolo, L., L'Astorina, A., Van Der Wal, R., & Gray, L. C. (2023). Recent contributions of citizen science on sustainability policies: A critical review. *Current Opinion in Environmental Science & Health*, *31*, 100423.

Damayanti, D. F., Solihat, R., & Hidayat, T. (2021). Upaya Meningkatkan Research Skill Siswa Melalui Citizen Science Project Pada Pembelajaran Biologi SMA. *BIOEDUKASI (Jurnal Pendidikan Biologi)*, *12*(2), 133–140.

Didenko, N., Popkova, A., Skripnuk, D., & Mirolyubova, O. (2017). Deforestation and human activity: A global perspective. *International Multidisciplinary Scientific GeoConference: SGEM*, *17*, 165–172.

Dunbar-Wallis, A., Jaeger, D., Suding, K., Littman, P., Baumgartner, L., Prater, M., Schuenemeyer, A., Tuff, K., Hogstad, A. B., & Alam, I. (2021). Creating study-specific tools to increase community and student engagement. *Citizen Science: Theory and Practice*, *6*(1).

Echeverria, A., Ariz, I., Moreno, J., Peralta, J., & Gonzalez, E. M. (2021). Learning plant biodiversity in nature: The use of the citizen–science platform inaturalist as a collaborative tool in secondary education. *Sustainability (Switzerland)*, *13*(2), 1–12. https://doi.org/10.3390/su13020735

Ellwood, E. R., Crimmins, T. M., & Miller-Rushing, A. J. (2017). Citizen science and conservation: Recommendations for a rapidly moving field. *Biological Conservation*, *208*, 1–4. https://doi.org/10.1016/j.biocon.2016.10.014

Erduran, S., Dagher, Z. R., Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing nature of science for science education*. Springer.

Estes-Zumpf, W., Addis, B., Marsicek, B., Lee, M., Nelson, Z., & Murphy, M. (2022). Improving sustainability of long-term amphibian monitoring: The value of collaboration and community science for indicator species management. *Ecological Indicators*, *134*, 108451. https://doi.org/10.1016/j.ecolind.2021.108451

Fernández-Álvarez, R., & Gutiérrez Ladrón de Guevara, M. de J. (2022). Socio-ecological patterns of citizens science programs: The case of forestry observations in 3 central Mexico states. *Urban Forestry and Urban Greening*, *70*(August 2021), 1–10. https://doi.org/10.1016/j.ufug.2022.127513

Fogg-rogers, L., Margarida, A., Csobod, E., Boushel, C., Laggan, S., & Hayes, E. (2024). Citizen-led emissions reduction : Enhancing enjoyment and understanding for diverse citizen engagement with air pollution and climate change decision making. *Environmental Science and Policy*, *154*(January), 103692. https://doi.org/10.1016/j.envsci.2024.103692

Follett, R., & Strezov, V. (2015). An analysis of citizen science based research: usage and publication patterns. *PloS One*, *10*(11), e0143687.

Forrest, S. A., Holman, L., Murphy, M., & Vermaire, J. C. (2019). Citizen science sampling programs as a technique for monitoring microplastic pollution: results, lessons learned and recommendations for working with volunteers for monitoring plastic pollution in freshwater ecosystems. *Environmental Monitoring and Assessment*, *191*, 1–10.

Garretson, A., Cuddy, T., Duffy, A. G., & Forkner, R. E. (2023). Citizen science data reveal regional heterogeneity in phenological response to climate in the large milkweed bug, Oncopeltus fasciatus. *Ecology and Evolution*, *13*(7), 1–16. https://doi.org/10.1002/ece3.10213

Gell, S., Pejkovic, E., & Heiss, R. (2023). How (Un-)Healthy are Austrian school food environments? Evidence from focus groups and citizen science. *Appetite*, *188*(June), 106636. https://doi.org/10.1016/j.appet.2023.106636

Giovos, I., Stoilas, V. O., Al-Mabruk, S. A. A., Doumpas, N., Marakis, P., Maximiadi, M., Moutopoulos, D., Kleitou, P., Keramidas, I., Tiralongo, F., & de Maddalena, A. (2019). Integrating local ecological knowledge, citizen science and long-term historical data for endangered species conservation: Additional records of angel sharks (Chondrichthyes: Squatinidae) in the Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(6), 881–890. https://doi.org/10.1002/aqc.3089

Greving, H., Bruckermann, T., Schumann, A., Straka, T. M., Lewanzik, D., Voigt-Heucke, S. L., Marggraf, L., Lorenz, J., Brandt, M., Voigt, C. C., Harms, U., & Kimmerle, J. (2022). Improving attitudes and knowledge in a citizen science project about urban bat ecology. *Ecology and Society*, *27*(2). https://doi.org/10.5751/ES-13272-270224

Gusti, U. A., Hamidah, N., Hidayat, T., & Sriyati, S. (2024). Analysis of Senior High School Students ' Understanding on Citizen Science Project in Indonesia. *Proceeding International Conference on Religion, Science and Education*, 421–425.

Haklay, M. (2015). *Citizen Science and Policy : A European Perspective* (E. Tyso (ed.); Vol. 4). The Woodrow Wilson Center.

Haklay, M. M., Dörler, D., Heigl, F., Manzoni, M., Hecker, S., & Vohland, K. (2021). What is citizen science? The challenges of definition. *The Science of Citizen Science*, *13*.

Harley, M. D., & Kinsela, M. A. (2022). CoastSnap: A global citizen science program to monitor changing coastlines. *Continental Shelf Research*, *245*(January), 104796. https://doi.org/10.1016/j.csr.2022.104796

Heinimäki, O.-P., Volet, S., Jones, C., Laakkonen, E., & Vauras, M. (2021). Student participatory role profiles in collaborative science learning: Relation of within-group configurations of role profiles and achievement. *Learning, Culture and Social Interaction*, *30*. https://doi.org/10.1016/j.lcsi.2021.100539

Herodotou, C., Ismail, N., Aristeidou, M., Miller, G., Benavides Lahnstein, A. I., Ghadiri Khanaposhtani, M., Robinson, L. D., & Ballard, H. L. (2022). Online Community and Citizen Science supports environmental science learning by young people. *Computers and Education*, *184*(April), 104515. https://doi.org/10.1016/j.compedu.2022.104515

Hsu, C., Chang, Y., & Liu, C. (2019). Can Short-Term Citizen Science Training Increase Knowledge , Improve Attitudes , and Change Behavior to Protect Land Crabs ? *Sustainability*, *11*(3918), 1–15.

Hyder, K., Townhill, B., Anderson, L. G., Delany, J., & Pinnegar, J. K. (2015). Can citizen science contribute to the evidence-base that underpins marine policy? *Marine Policy*, *59*, 112–120.

Irwin, A. (1995). *Citizen Science A Study of People, Expertise and Sustainable Development*. Routledge. https://doi.org/https://doi.org/10.4324/9780203202395

Johnson, B. A., Mader, A. D., Dasgupta, R., & Kumar, P. (2020). Citizen science and invasive alien species: An analysis of citizen science initiatives using information and communications technology (ICT) to collect invasive alien species observations. *Global Ecology and Conservation*, *21*, e00812.

Jones, J. S., Guézou, A., Medor, S., Nickson, C., Savage, G., Alarcón-Ruales, D., Galloway, T. S., Muñoz-Pérez, J. P., Nelms, S. E., Porter, A., Thiel, M., & Lewis, C. (2022a). Microplastic distribution and composition on two Galápagos island beaches, Ecuador: Verifying the use of citizen science derived data in long-term monitoring. *Environmental Pollution*, *311*. https://doi.org/10.1016/j.envpol.2022.120011

Jones, J. S., Guézou, A., Medor, S., Nickson, C., Savage, G., Alarcón-Ruales, D., Galloway, T. S., Muñoz-Pérez, J. P., Nelms, S. E., Porter, A., Thiel, M., & Lewis, C. (2022b). Microplastic distribution and composition on two Galápagos island beaches, Ecuador: Verifying the use of citizen science derived data in long-term monitoring. *Environmental Pollution*, *311*(July). https://doi.org/10.1016/j.envpol.2022.120011

Joubert, I. A., Geppert, M., Ess, S., Nestelbacher, R., Gadermaier, G., Duschl, A., Bathke, A. C., & Himly, M. (2020). Public perception and knowledge on nanotechnology: A study based on a citizen science approach. *NanoImpact*, *17*(November 2019), 100201. https://doi.org/10.1016/j.impact.2019.100201

Kiessling, T., Knickmeier, K., Kruse, K., Gatta-Rosemary, M., Nauendorf, A., Brennecke, D., Thiel, L., Wichels, A., Parchmann, I., Körtzinger, A., & Thiel, M. (2021). Schoolchildren discover hotspots of floating plastic litter in rivers using a large-scale collaborative approach. *Science of the Total Environment*, *789*. https://doi.org/10.1016/j.scitotenv.2021.147849

Kummer, D. M., & Turner, B. L. (1994). The human causes of deforestation in Southeast Asia. *Bioscience*, *44*(5), 323–328.

Li, B., Liang, W., Liu, Q.-X., Fu, S., Ma, C., Chen, Q., Su, L., Craig, N. J., & Shi, H. (2021). Fish ingest microplastics unintentionally. *Environmental Science & Technology*, *55*(15), 10471–10479.

Lloyd, T. J., Fuller, R. A., Oliver, J. L., Tulloch, A. I., Barnes, M., & Steven, R. (2020). Estimating the spatial coverage of citizen science for monitoring threatened species. *Global Ecology and Conservation*, *23*, e01048. https://doi.org/10.1016/j.gecco.2020.e01048

Loiselle, S., Bishop, I., Moorhouse, H., Pilat, C., Koelman, E., Nelson, R., Clymans, W., Pratt, J., & Lewis, V. (2024). Citizen scientists filling knowledge gaps of phosphate pollution dynamics in rural areas. *Environmental Monitoring and Assessment*, *196*(2), 1–15. https://doi.org/10.1007/s10661-024-12389-5

Longo, A., Zappatore, M., & Bochicchio, M. A. (2020). Apollon: Towards a citizen science methodology for urban environmental monitoring. *Future Generation Computer Systems*, *112*, 899–912. https://doi.org/10.1016/j.future.2020.06.041

Maharani, N., Kusrini, M. D., & Hamidy, A. (2022). Increasing Herpetofauna Data Through Citizen Science in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *950*(1). https://doi.org/10.1088/1755-1315/950/1/012063

Mason, L., & Arathi, H. S. (2019). Assessing the efficacy of citizen scientists monitoring native bees in urban areas. *Global Ecology and Conservation*, *17*, e00561. https://doi.org/10.1016/j.gecco.2019.e00561

McCormick, A. R., & Hoellein, T. J. (2016). Anthropogenic litter is abundant, diverse, and mobile in urban rivers: Insights from cross-ecosystem analyses using ecosystem and community ecology tools. *Limnology and Oceanography*, *61*(5), 1718–1734.

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., Evans, D. M., French, R. A., Parrish, J. K., Phillips, T. B., Ryan, S. F., Shanley, L. A., Shirk, J. L., Stepenuck, K. F., Weltzin, J. F., Wiggins, A., Boyle, O. D., Briggs, R. D., Chapin, S. F., … Soukup, M. A. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, *208*, 15–28. https://doi.org/10.1016/j.biocon.2016.05.015

Meijer, L. J. J., Van Emmerik, T., Van Der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, *7*(18), eaaz5803.

Meschini, M., Prati, F., Simoncini, G. A., Airi, V., Caroselli, E., Prada, F., Marchini, C., Machado Toffolo, M., Branchini, S., Brambilla, V., Covi, C., & Goffredo, S. (2021). Environmental Awareness Gained During a Citizen Science Project in Touristic Resorts Is Maintained After 3 Years Since Participation. *Frontiers in Marine Science*, *8*(February), 1–11. https://doi.org/10.3389/fmars.2021.584644

Muaziyah, S. E. S., Hidayat, T., Sriyati, S., & Lutianasari, L. (2023). Implementation of the Merdeka Curriculum Using Citizen Science Project Weather-it to Improve Critical Thinking Skills of Junior High School Students. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1470–1479. https://doi.org/10.29303/jppipa.v9i3.2277

Nemec, Z. C., Cooper, K. N., & Clark, J. M. (2022). Implementing the FrogWatch USA Citizen Science Program as a Versatile Ecological Educational Tool. *The American Biology Teacher*, *84*(8), 503–505.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment*, *10*(6), 298–304.

Njue, N., Kroese, J. S., Gräf, J., Jacobs, S. R., Weeser, B., Breuer, L., & Rufino, M. C. (2019). Citizen science in hydrological monitoring and ecosystem services management: State of the art and future prospects. *Science of the Total Environment*, *693*, 133531.

Oturai, N. G., Syberg, K., Fraisl, D., Hooge, A., Ramos, T. M., Schade, S., & Hansen, S. F. (2023). UN plastic treaty must mind the people: Citizen science can assist citizen involvement in plastic policymaking. *One Earth*, *6*(6), 715–724. https://doi.org/https://doi.org/10.1016/j.oneear.2023.05.017

Pandeya, B., Buytaert, W., & Potter, C. (2021). Designing citizen science for water and ecosystem services management in data-poor regions: Challenges and opportunities. *Current Research in Environmental Sustainability*, *3*, 100059. https://doi.org/10.1016/j.crsust.2021.100059

Pernat, N., Gathof, A. K., Herrmann, J., Seitz, B., & Buchholz, S. (2023). Citizen Science Apps in a Higher Education Botany Course: Data Quality and Learning Effects. *Sustainability (Switzerland)*, *15*(17). https://doi.org/10.3390/su151712984

Phillips, T. B., Ballard, H. L., Lewenstein, B. V, & Bonney, R. (2019). Engagement in science through citizen science: Moving beyond data collection. *Science Education*, *103*(3), 665–690.

Potsikas, M., Prouska, K., Efthimiou, G., Plakitsi, K., & Kornelaki, A. C. (2023). Citizen science practice around Lake Pamvotis and the Ioannina Castle: Using iNaturalist to foster connectedness to nature in citizens and university students. *International Journal of Geoheritage and Parks*, *11*(3), 450–463. https://doi.org/10.1016/j.ijgeop.2023.07.002

Rachmawati, N., Hidayat, T., & Supriatno, B. (2022). Analysis of Citizen Science-Based Flowering Plant Diversity Worksheet Development to Improve Students' Critical Thinking

Ability. *Bioedukasi*, *20*(2), 38. https://doi.org/10.19184/bioedu.v20i2.34613

Raddick, M. J., Prather, E. E., & Wallace, C. S. (2019). Galaxy zoo: Science content knowledge of citizen scientists. *Public Understanding of Science*, *28*(6), 636–651.

Rameshbhai Patel, H., & Joseph, J. M. (2016). Questionnaire Designing Process: A Review. *Journal of Clinical Trials*, *06*(02). https://doi.org/10.4172/2167-0870.1000255

Redmon, J. H., Levine, K. E., Aceituno, A. M., Litzenberger, K., & Gibson, J. M. D. (2020). Lead in drinking water at North Carolina childcare centers: Piloting a citizen science-based testing strategy. *Environmental Research*, *183*(January), 109126. https://doi.org/10.1016/j.envres.2020.109126

Roche, J., Bell, L., Galvão, C., Golumbic, Y. N., Kloetzer, L., Knoben, N., Laakso, M., Lorke, J., Mannion, G., & Massetti, L. (2020). Citizen science, education, and learning: Challenges and opportunities. *Frontiers in Sociology*, *5*, 613814.

Scaini, C., Peresan, A., Tamaro, A., Poggi, V., & Barnaba, C. (2022). Can high-school students contribute to seismic risk mitigation? Lessons learned from the development of a crowd-sourced exposure database. *International Journal of Disaster Risk Reduction*, *69*(December 2021), 102755. https://doi.org/10.1016/j.ijdrr.2021.102755

Scheibner, J., Jobin, A., & Vayena, E. (2021). Ethical issues with using Internet of Things devices in citizen science research: a scoping review. *Frontiers in Environmental Science*, *9*, 629649.

Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environmental Science & Technology*, *51*(21), 12246–12253.

Segev, T., Harvey, A. P., Ajmani, A., Johnson, C., Longfellow, W., Vandiver, K. M., & Hemond, H. (2021). A case study in participatory science with mutual capacity building between university and tribal researchers to investigate drinking water quality in rural Maine. *Environmental Research*, *192*(November 2020), 110460. https://doi.org/10.1016/j.envres.2020.110460

Shaw, J., Cunningham, C., Harper, S., Ragazzon-Smith, A., Lythgoe, P. R., & Walker, T. R. (2023). Biomonitoring of honey metal(loid) pollution in Northwest England by citizen scientists. *Environmental Advances*, *13*(June), 100406. https://doi.org/10.1016/j.envadv.2023.100406

Silver, L. (2019). *Smartphone Ownership Is Growing Rapidly Around the World, but Not Always Equally*. Pew Research Center. https://www.pewresearch.org/global/2019/02/05/smartphone-ownership-is-growing-rapidly-around-the-world-but-not-always-equally/

Singh, S. (2021). Energy Crisis and Climate Change: Global Concerns and Their Solutions. *Energy: Crises, Challenges and Solutions*, 1–17.

Smith, H. E., Cooper, C. B., Busch, K. C., Harper, S., Muslim, A., McKenna, K., & Cavalier, D. (2023). Facilitator organizations enhance learning and action through citizen science: a case study of Girl Scouts' Think Like a Citizen Scientist journey on SciStarter. *Environmental Education Research*, *0*(0), 1–22. https://doi.org/10.1080/13504622.2023.2237705

Soga, M., & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment*, *14*(2), 94–101.

Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., & Kelling, S. (2009). *eBird* : A citizen-based bird observation network in the biological sciences. *Biological Conservation*, *142*(10), 2282–2292.

Susbiyanto, S., Hidayat, T., Surkanti, H., & Riandi. (2024). Perception of Citizen Science Project in Ecology Courses Using Rasch Measurement Model. *KnE Social Scieencence*, *16057*.

Thompson, M. M., Moon, K., Woods, A., Rowley, J. J. L., Poore, A. G. B., Kingsford, R. T., & Callaghan, C. T. (2023). Citizen science participant motivations and behaviour: Implications for biodiversity data coverage. *Biological Conservation*, *282*, 110079. https://doi.org/https://doi.org/10.1016/j.biocon.2023.110079

Toerpe, K. (2013). The rise of citizen science. *The Futurist*, *47*(4), 25.

Toftum, J., & Clausen, G. (2023). Classroom airing behaviour significantly affects pupil well-being and concentration performance – Results of a large-scale citizen science study in Danish schools. *Energy and Buildings*, *286*, 112951. https://doi.org/10.1016/j.enbuild.2023.112951

UNRP. (2015). *Sustainable development goals*.

Vigneswaran, C., Afifah Zaynab, M., Keerthana, J., Harish Krishna, R., & Hariharan, R. (2022). Design and Development of River Water Trash Collector for a Sustainable Environment. In *Materials, Design and Manufacturing for Sustainable Environment: Select Proceedings of ICMDMSE 2022* (pp. 589–600). Springer.

Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perello, J., Ponti, M., Samson, R., & Wagenknecht, K. (2021). The science of citizen science. *The Science of Citizen Science*, 1–529. https://doi.org/10.1007/978-3-030-58278-4

von Gönner, J., Bowler, D. E., Gröning, J., Klauer, A. K., Liess, M., Neuer, L., & Bonn, A. (2023). Citizen science for assessing pesticide impacts in agricultural streams. *Science of the Total Environment*, *857*(October 2022). https://doi.org/10.1016/j.scitotenv.2022.159607

von Gönner, J., Gröning, J., Grescho, V., Neuer, L., Gottfried, B., Hänsch, V. G., Molsberger-Lange, E., Wilharm, E., Liess, M., & Bonn, A. (2024). Citizen science shows that small agricultural streams in Germany are in a poor ecological status. *Science of the Total Environment*, *922*(February). https://doi.org/10.1016/j.scitotenv.2024.171183

Votier, S. C., Archibald, K., Morgan, G., & Morgan, L. (2011). The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Marine Pollution Bulletin*, *62*(1), 168–172.

Wagenknecht, K., Woods, T., Sanz, F. G., Gold, M., Bowser, A., Rüfenacht, S., Ceccaroni, L., & Piera, J. (2021). EU-Citizen. Science: A platform for mainstreaming citizen science and open science in Europe. *Data Intelligence*, *3*(1), 136–149.

Wangyal, J. T., Bower, D., Vernes, K., & Thinley, P. (2022a). Employing citizen science to understand amphibian and reptile diversity and distribution in the Himalayan Kingdom of Bhutan. *Global Ecology and Conservation*, *37*(May), e02157. https://doi.org/10.1016/j.gecco.2022.e02157

Wangyal, J. T., Bower, D., Vernes, K., & Thinley, P. (2022b). Employing citizen science to understand amphibian and reptile diversity and distribution in the Himalayan Kingdom of Bhutan. *Global Ecology and Conservation*, *37*. https://doi.org/10.1016/j.gecco.2022.e02157

Webster, S. E., Landry, J. B., Laumann, K. M., Swanson, S., & Dennison, W. C. (2021). Co-creating and evaluating a citizen science program for monitoring submerged aquatic vegetation in Chesapeake Bay. *Regional Studies in Marine Science*, *46*, 101906. https://doi.org/10.1016/j.rsma.2021.101906

Wichmann, C. S., Fischer, D., Geiger, S. M., Honorato-Zimmer, D., Knickmeier, K., Kruse, K., Sundermann, A., & Thiel, M. (2022). Promoting pro-environmental behavior through citizen science? A case study with Chilean schoolchildren on marine plastic pollution. *Marine Policy*, *141*(May), 105035. https://doi.org/10.1016/j.marpol.2022.105035