Citizen science as a valuable tool for environmental review

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Human development and population growth are placing immense pressure on natural ecosystems, necessitating the establishment of a balance between development and biodiversity preservation. Citizen science may serve as a valuable resource for monitoring biodiversity and informing decision-making processes, but its use has not been investigated within the realm of environmental review. We sought to quantify the extent to which citizen science data are currently being used, mentioned, or suggested in environmental impact statements (EISs) by analyzing more than 1300 EISs produced under the US National Environmental Policy Act. Among the sampled EISs, we found increasing incorporation of citizen science within the environmental review process, with 40% of EISs in 2022 using, mentioning, or suggesting use of such information, as compared with just 3% in 2012. Citizen science offers substantial potential to enhance biodiversity monitoring and conservation efforts within environmental review, but numerous considerations must be broadly discussed before citizen science data can be widely adopted.

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Human pressures on nature are increasingly pervasive (Bowler *et al.* 2020), with a growing human population inevitably leading to ever-expanding building and development projects (eg infrastructure, urban expansion, resource extraction). Maintaining biodiversity and the benefits it provides to humanity (Pimentel *et al.* 1997) should be a critical goal as future development projects are planned. Governments, developers, and society in general need tools that help reconcile future development and mitigate biodiversity loss (Simmonds *et al.* 2020).

Currently, many local, state, and federal governments around the world have laws and policies in place to help mitigate biodiversity loss from development projects (Glasson and Therivel 2013). A key part of this policy process typically involves an environmental review of the potential socioenvironmental impacts of a particular project, and the identification of strategies to mitigate impacts, such as minimizing biodiversity loss (Morris and Therivel 2001; Glasson and Therivel 2013). Although such laws and policies tend to focus on threatened and endangered species, mandates generally exist for agencies to consider how actions will affect biodiversity as a whole (CEQ 1993, 2021). In the US, for example, the National Environmental Policy Act (NEPA) mandates environmental reviews for any federal project with the potential for major impacts on the environment (Emerson *et al.* 2022). After its enactment in 1970, NEPA has been emulated by more than 194 states, provinces, and countries around the world. In the US and many countries, environmental reviews are overseen by federal and state agencies, and occasionally the associated work of data collection and analysis involves professional consulting firms. This professional field (hereafter referred to as "environmental consulting") plays a critical role in the goal of reducing impacts to biodiversity (Glasson and Therivel 2013).

One of the first steps in developing an environmental impact assessment is to document and quantify the organisms present on the planned site of development (Morris and Therivel 2001). In an ideal world, given the potential for major environmental impacts, each project would begin with thorough biodiversity surveys to ensure that species are properly documented. However, such surveys are often cost-, labor- and time-intensive, leading agency officials and environmental consultants to sometimes rely on existing sources of information about species presence.

Citizen science, alternatively referred to as community or participatory science, now accounts for the majority of biodiversity data being collected globally (Callaghan *et al.* 2023).

In a nutshell:

- Under the US National Environmental Policy Act, environmental impact statements (EISs) are mandated for development projects that may have major environmental impacts
- EISs are increasingly incorporating citizen science data to document and quantify the organisms present or absent on the planned site of development in lieu of or as a means of complementing expensive and time-consuming biodiversity surveys
- Although citizen science data have potential for informing decisions, their use in EISs must be scientifically sound and statistically rigorous, in accordance with general ecological and conservation science practices

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As such, citizen science is frequently touted as a potential mechanism for biodiversity monitoring (Tulloch *et al.* 2013; Chandler *et al.* 2017; McKinley *et al.* 2017), especially given its cost-effectiveness combined with the broad spatial, temporal, and taxonomic scope of the collected data. However, these calls most often revolve around government and "public" entities, for example, in monitoring progress toward achieving the UN Sustainable Development Goals (Fraisl *et al.* 2020), or the ability to use citizen science in governmental monitoring schemes (Hadj-Hammou *et al.* 2017).

The role of citizen science in environmental reviews in general, and in the private sector in particular, has been neglected as a potential field of exploration. Anecdotally, the scientific community is aware that environmental consultants may use citizen science data to inform their work. A more comprehensive understanding of how citizen science data are being used in environmental reviews is critical, given the implications for policy-relevant decision making. As an example, citizen science data are associated with many types of spatial and temporal biases, including proportionally more sampling near regions with high human population density or more observations in recent years as compared with historical records, often influencing our understanding of biodiversity (Bowler *et al.* 2022). Are these biases properly accounted for as part of the environmental review? Are citizen science data being used to provide documentation of endangered and/or threatened species at a site? And how often are these data being used to inform environmental review?

Here, we seek to address these questions by highlighting a currently overlooked but promising source of data—namely, biodiversity data originating from citizen science projects—that agency officials and environmental consultants may use to complement environmental review processes. First, we quantify the extent to which citizen science data are currently being used or mentioned in environmental review by analyzing a corpus of environmental impact statements (EISs) produced under NEPA that is housed at NEPAccess.org (the largest and most comprehensive repository of US federal EISs). We then provide an overview of selected possible advantages and disadvantages of the use of citizen science data in environmental reviews and by environmental consulting firms. Finally, we consider future avenues to broaden the potential of citizen science data in environmental reviews, including recommendations relevant for decision makers and agency officials who oversee environmental review processes.

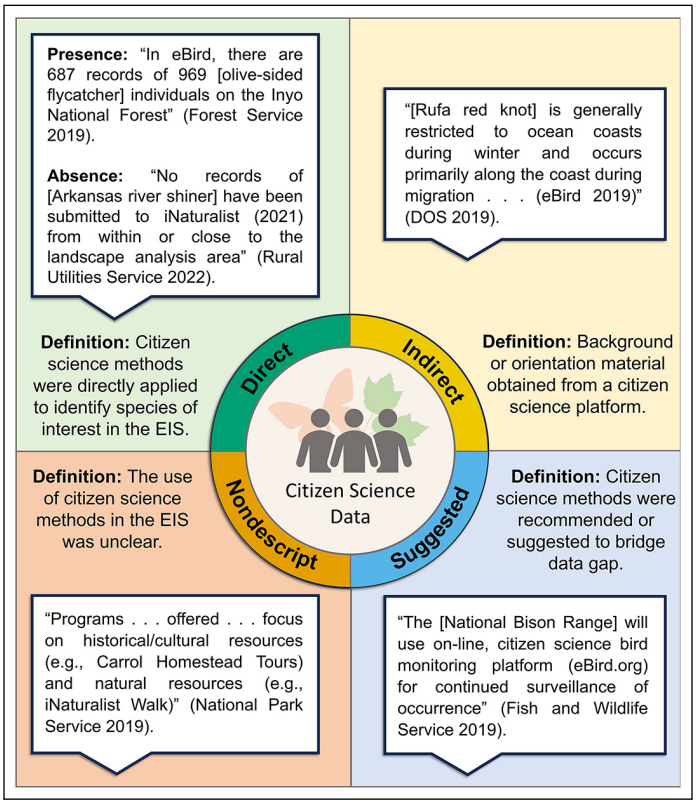

Figure 1. Defined citizen science data usage types observed in environmental impact statements (EISs). Quotations from EIS documents, categorized by use type, appear in the white boxes. References for these EISs are provided in Appendix S1: Panel S2. Silhouettes courtesy of Microsoft 365 PowerPoint [people] and PhyloPic (www.phylopic.org; CC0 1.0 Universal) [plant and butterfly].

Quantifying the current use of citizen science data in EISs

To gain an understanding of the current use of biodiversity-focused (eg plant- and animal-focused) citizen science data in environmental consulting, we searched EISs for the following keywords: "citizen science", "community science", "eBird", and "iNaturalist". We constrained our search to eBird and iNaturalist because these are the most popular and widely used citizen science projects throughout the US, matching the extent of our analysis.

We used NEPAccess as a platform for finding and analyzing decades of applied science and records of public participation in US environmental decision-making processes to identify EISs completed between 2012 and 2022. NEPAccess covers the period from 1970 to the present, and includes full-text searchable PDFs of EISs, Environmental Protection Agency (EPA) metadata records since 2012, and additional metadata developed by the NEPAccess team. At the time our search was conducted (in February 2023), NEPAccess.org was the most comprehensive source of NEPA documentation in the US, containing more EISs and more metadata than the EPA platform (https://about.nepaccess.org).

To investigate how citizen science data were used in each EIS document, we coded the mention and use of citizen science as one of four options: direct use, indirect use, nondescript/inconclusive use, or encouraged/suggested use (Figure 1; see Appendix S1: Panel S1 for formal definitions). For an EIS, direct use was coded when citizen science played a pivotal role in directly influencing a decision within the assessment. This often involved using citizen science data to identify and

document the presence or absence of species near the project area. Indirect use was coded when citizen science was utilized as a supplementary resource for the analysis, providing background or reference data without directly influencing a decision within the assessment. Nondescript/inconclusive was coded when either we could not determine the reason that citizen science was being used or when citizen science was only briefly mentioned. Encouraged/suggested use was coded when citizen science data were not included in the analysis but their use was suggested to fill a knowledge gap or as a part of the project's objectives. In addition, we noted the lead agency of the EIS (eg US Fish and Wildlife Service, Bureau of Land Management [BLM]). Of the 1355 EISs in the NEPAccess repository that were completed between 2012 and 2022, 253 matched our keyword search; of these, 25 were false positives (see Appendix S1: Panel S1) and were therefore excluded from analysis. The remaining 228 EISs encompassed all states except Nebraska, with California having the highest coverage (n = 75; Appendix S1: Figure S1).

Between 2012 and 2022, 17% of all EISs (228 out of 1355) mentioned or used citizen science data. Upon examination, we found that the proportion of EISs mentioning or using citizen science data increased over time, with the highest proportion (40%) occurring in 2022 (Figure 2). EISs using citizen science data were present across 45 agencies, most commonly among the US Army Corps of Engineers (n = 38), US Forest Service (n = 26), and BLM (n = 24) (Appendix S1: Figure S2). Of the 228 EISs that mentioned or used citizen science, 147 (64%) had direct use of citizen science data, with eBird as the most popular source (88% of direct use cases) and iNaturalist used by only a fraction thereof (6%) (Table 1): for example, these data were used to document the number of individuals and number of records for species of interest in a particular focal geographic area (Figure 1). We also found that 43 EISs (19% of the aforementioned 228 EISs) had indirect use of citizen science data: for example, using an iNaturalist-derived species range to make a statement about animal biology. Notably, of the direct use cases, 28 EISs (19% of the aforementioned 147 direct use EISs) relied on "no sighting" of a species as evidence of absence for that species (Figure 1). An additional 46 EISs (20% of the aforementioned 228 EISs) suggested or encouraged future use of citizen science: for example, by aiming to increase local participation and enhancing local interest in nearby natural resources (Figure 1).

Our results highlight a previously undocumented use of citizen science data, that of inclusion in environmental review and regulatory processes, forming a data contribution to EISs. Our analysis also points to the current, and increasing, use of citizen science since 2012, mimicking the popularity of citizen science in the broader biodiversity research field (Pocock *et al.* 2017). At the same time, our results illustrate the future potential of citizen science data in environmental review, with an increasing number of EISs suggesting and encouraging future use of citizen science participation. Yet, how citizen science is further implemented in environmental review is worthy of more discussion. Appropriate use of citizen science data, in which potential biases in the data are statistically accounted for, is critical to make scientifically sound decisions. For example, data from iNaturalist are buffered for threatened species, where the precise coordinates are most often not known to the public, but whether or how this was taken into consideration was not always clear. Another example that warrants discussion is that of statistically accounting for the number of records within the region of interest, which is related to

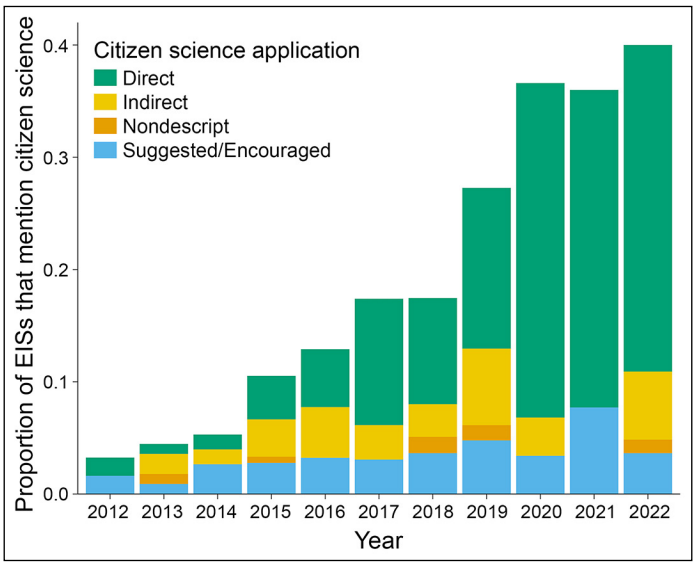

Figure 2. Proportion of EISs returned from our search about citizen science between 2012 and 2022, categorized by use type.

Table 1. Number of environmental impact statements (EISs) categorized by citizen science application, data usage, and data source

Category	Number of EISs
Citizen science application	
Direct	147
Indirect	43
Nondescript	10
Suggested/encouraged	46
Data usage	
Presence	139
Absence	28
Data source	
iNaturalist	9
eBird	129
Citizen/community science	36

Notes: the citizen science application, data usage, and data sources categories are not exclusive (ie a paper that uses iNaturalist and eBird data will be included in both categories). Data usage conveys whether citizen science data were used to document species presence or species absence and is only applicable for direct use citizen science application. Citizen/community science referred to other citizen science platforms and projects (eg Christmas bird count, federal government citizen science initiatives) or general statements about citizen science without describing a specific platform.

the detection probability for a given species. Detection probability also may vary among species; for instance, large-bodied species are more detectable than small-bodied species (Callaghan *et al.* 2021a). Such biases need to be considered prior to the incorporation of citizen science data in an environmental review. Nevertheless, the number of EISs using or mentioning citizen science to some degree warrants further consideration for how environmental reviews should be implemented in the future, as well as the policies that influence their implementation.

The potential value of citizen science for environmental review

We identified an increase in the inclusion of citizen science data in environmental review. However, there remains much potential for expanded use of citizen science in such reviews. The use of citizen science in environmental review could include agencies and consultants interacting with volunteers directly, for instance by working with local volunteers to collect data at a specific site or hosting a bioblitz at a site of planned development. Alternatively, citizen science can be relied on indirectly by agencies and consultants in reviews by using data originating from citizen science projects (ie indirectly working with volunteers). An obvious benefit of using citizen science data is the potential for increased data collection over many years and with broad geographic extent. Citizen scientists tend to participate in projects because they want to contribute to science, and specifically to conservation (Domroese and Johnson 2017; Larson *et al.* 2020). Because of this intrinsic interest, citizen science participants tend to be devoted and exceptional naturalists (Cooper 2016) with an ability and dedication to detect even the rarest species—arguably the species that are the most important for EISs, given that, from a regulatory standpoint, even a single occurrence can be meaningful.

Increasing public engagement in the environmental review process could have many flow-on effects. Research has shown that participation in citizen science projects can influence knowledge gain and behavioral change (Jordan *et al.* 2011) and that engagement can lead to increased scientific literacy (Phillips *et al.* 2019). Therefore, direct participation in the environmental review process could likely lead to more educated voters who support legislation for biodiversity-friendly development practices, as well as a more generally aware public about environmental decision-making processes and policies. Indeed, the need for public engagement is recognized in the NEPA statute (CEQ 2021). By regulation, public participation is required at two points during the environmental review process: public input is requested during the early "scoping" stage of projects, and the public is asked to officially comment on draft EISs (Glucker *et al.* 2013; Ulibarri *et al.* 2019). The Council on Environmental Quality (CEQ), the unit within the Executive Office of the President that oversees NEPA, recently updated the NEPA regulations for only the fourth time since 1970 (CEQ 2024). The new rules give agencies increased flexibility to tailor public engagement to their specific programs and actions, which could include citizen science programs targeted to support environmental review.

Further considerations of using citizen science data in environmental consulting

Although inclusion of citizen science data holds great potential for advancing and increasing the power of decision making using EISs, further considerations are worth discussing.

First, it is important to understand the extent to which participants of citizen science projects are willing to allow the data they collect to be used by a professional environmental consulting firm. A major motivation of citizen science participants is to contribute to conservation (Maund *et al.* 2020), and conservation-minded people may be opposed to development (McBeth and Shanahan 2004). Therefore, citizen science participants could possibly feel empowered knowing that they are potentially contributing to conservation policy directly, for instance by detecting and documenting a rare species that could influence a NEPA outcome. In contrast, getting direct buy-in from potential citizen science participants regarding the contribution of data to the environmental review process could be challenging if those data are used by a for-profit business, such as an environmental consulting firm. Alternatively, citizen science participants might be willing to be compensated for their time.

Second, the use of citizen science data requires a nuanced understanding of the data and appropriate statistical analysis and thus conclusions about biodiversity. Of the EISs that directly involved citizen science data, 12% (28 out of 228) used those data as evidence of species absence. However, there are many biases and gaps in organisms' presence associated with citizen science data, including human preferences (eg people are more likely to observe and report brightly colored, charismatic species than cryptic, less charismatic species), and time of sampling (eg observations are more likely to come from periods of the year when sampling is more convenient). It is unlikely that project sites and adjacent areas will necessarily have been sampled by citizen science participants to such an extent as to provide sufficient evidence that an organism was not present. Given that species can sometimes go undetected and that the presence and frequency of citizen science records vary, and are often associated with the relative proximity to human population centers (Bird *et al.* 2014), we caution against concluding that an organism is absent based solely on an absence of documentation.

Future avenues for broadening the use of citizen science in environmental review

As illustrated, there are both potential benefits of and drawbacks to the future inclusion of citizen science data in the environmental review process. Below, we outline selected research avenues that could help lead to an improved understanding of the role of citizen science, and thus its positioning, in environmental review in the future.

Broaden the scope of EISs included in analyses

A further refinement of our understanding of how citizen science is used in EISs is necessary. Here, we focused only on environmental reviews at the federal level under NEPA. We did not include state- and county-level analyses, another area worthy of future exploration. Because our analyses focused on EISs at the federal level, we also did not account for many environmental review projects that take place on private land, for which citizen science data may be less available.

Encourage data sharing reciprocity whenever possible

Environmental consulting firms should share their data with citizen science repositories. For example, bird surveys commissioned by environmental consulting firms could be submitted to eBird and information about other organisms could be submitted to iNaturalist. Sharing data with the scientific community and the public could help encourage others to make their data available and thus enhance reciprocity. However, we recognize that identifying the legal owner of data collected by environmental consulting firms is often challenging and potentially complicates data sharing.

Optimize sampling effort by citizen scientists

Many citizen science participants are eager to help conservation efforts and protect biodiversity (Maund *et al.* 2020). One promising avenue of future research includes optimizing how and where citizen science participants collect data (Callaghan *et al.* 2019; 2021b; 2023). If potential development plans are known, then citizen science participants could be mobilized to collect data from the locations in which observations would be most valuable, for instance to better document a species of concern at a potential development site.

Produce policy-relevant guidelines on how citizen science should be used in EISs

We do not provide guidelines on how citizen science data could be used in environmental reviews here, but production of potential guidelines that include guidance on statistical analysis is an important step that must be addressed before citizen science data are used more frequently in environmental review. For US federal environmental reviews under NEPA, the guidelines would need to be produced by, or with, the CEQ.

Conclusions

As the global population continues to increase and become more urbanized, issues surrounding development and its associated policies assume greater importance. Quantifying how and what biodiversity is present is essential for effective mitigation of biodiversity loss. Citizen science is an increasingly valuable data source for biodiversity researchers and scientists. Environmental review is a critically important, but often overlooked, component of biodiversity monitoring and conservation. Our objective here was to raise awareness of the potential advantages and disadvantages of the use of citizen science in EISs, using those previously submitted in the US under NEPA as a case study. It is our hope that our findings will spur further discussion about the relevance and value of citizen science data in the environmental review process. We believe that biodiversity monitoring, and biodiversity conservation more broadly, will benefit from increased use and participation of citizen science within the domains of environmental review and environmental consulting.

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Data Availability Statement

Our coded dataset—listing the environmental impact statements' titles and agency, as well as our coding of the environmental impact statement—is available in Callaghan *et al.* (2024) on Zenodo at https://doi.org/10.5281/zenodo.12205792.

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Supporting Information

Additional material can be found online at http://onlinelibrary.wiley.com/doi/10.1002/fee.2808/suppinfo