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PERSPECTIVE

A framework for contextualizing social-ecological biases in contributory science data

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Abstract

1. Contributory science—including citizen and community science—allows scientists to leverage participant-generated data while providing an opportunity for engaging with local community members. Data yielded by participant-generated biodiversity platforms allow professional scientists to answer ecological and evolutionary questions across both geographic and temporal scales, which is incredibly valuable for conservation efforts.
2. The data reported to contributory biodiversity platforms, such as eBird and iNaturalist, can be driven by social and ecological variables, leading to biased data. Though empirical work has highlighted the biases in contributory data, little work has articulated how biases arise in contributory data and the societal consequences of these biases.
3. We present a conceptual framework illustrating how social and ecological variables create bias in contributory science data. In this framework, we present four filters—*participation*, *detectability*, *sampling* and *preference*—that ultimately shape the type and location of contributory biodiversity data. We leverage this framework to examine data from the largest contributory science platforms—eBird and iNaturalist—in St. Louis, Missouri, the United States, and discuss the potential consequences of biased data.
4. Lastly, we conclude by providing several recommendations for researchers and institutions to move towards a more inclusive field. With these recommendations,

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we provide opportunities to ameliorate biases in contributory data and an opportunity to practice equitable biodiversity conservation.

KEYWORDS
biases, biodiversity, citizen science, community science, eBird, iNaturalist, participatory science, St. Louis

1 | INTRODUCTION

Biological data collected by the general public through participatory science initiatives is an extraordinary opportunity for scientists to engage with local communities in studying the natural world. *Participatory science* is an umbrella term that captures the plurality of approaches that exist across disciplines and describes the data collected by *participants*. There are three major participatory science typologies, with (i) co-created and (ii) collaborative projects tending to better include vast identities, livelihoods, experiences and knowledge than (iii) *contributory science* (Shirk et al., 2012). Most *large-scale* participatory science projects are contributory, which is the most common approach used in ecology and biogeography (e.g. eBird, iNaturalist and NestWatch).

With the increased availability of cell phones equipped with cameras and GPS capabilities and the launch of digital applications such as *eBird* and *iNaturalist*, contributory science projects can produce fine-scale geolocated data, which is now the largest source of biodiversity data (Chandler et al., 2017). These advances in access to technology have increased the utility of participant-generated data for natural scientists and inspired new research questions. For instance, these data have documented the presence and range of rare species and morphs (Borzée et al., 2019; Wesener, 2018; Worthington et al., 2012), tracked non-native species (Gallo & Waitt, 2011; Larson et al., 2020) and revealed organismal responses to climate change and human activity (Champion et al., 2018; Des Roches et al., 2022; Sanderfoot et al., 2022; Senzaki et al., 2020). These efforts can be mutually beneficial, resulting in greater personal agency and political participation (Ballard, Dixon, et al., 2017; Conrad & Hilchey, 2011; Overdevest et al., 2004), a connection to civic and legal forums that provide legitimacy to public input (McCormick, 2012), a sense of advocacy for environmental action (Ballard, Robinson, et al., 2017; Cornwell & Campbell, 2012), increased accountability and industrial compliance with regulatory agencies (Overdevest & Mayer, 2007) and a strengthened sense of community belonging and care of the local environment (Haywood et al., 2016, 2021; Newman et al., 2017; Toomey et al., 2020). Moreover, open access to these biodiversity data provides a cost-effective approach to managing wildlife habitats and populations (Aceves-Bueno et al., 2015; Goldstein et al., 2014).

Despite the widespread benefits of contributory data, recurrent *spatial biases* and temporal *biases* can sabotage or dilute the applicability of such efforts. With contributory data, sampling locations and objectives are generally not predefined, and participants autonomously choose to collect data on certain organisms in certain areas (Roth, 2021). Historical legacies of injustice serve as the undercurrent of this supposed 'autonomy', as oppressive societal forces, such as apartheid and societal housing arrangements, constrain and dictate how participants of varying racial, ethnic, gender and socioeconomic identities navigate spaces (Finney, 2014; Gadsden et al., 2023; Wesely & Gaarder, 2004). Would-be participants consequently select areas and environments they perceive as safe or have access to (Finney, 2014). In addition, studies from the United States and the United Kingdom show that contributory data are overwhelmingly collected by white *community* members (Allf et al., 2022; Curtis, 2015; Mahmoudi et al., 2022; Pateman et al., 2021), with participation declining as wealth decreases (Mac Domhnaill et al., 2020; Mahmoudi et al., 2022; Pateman et al., 2021). Furthermore, areas of environmental justice concern (e.g. poor air and water quality, and high toxicant levels) are frequently underrepresented (Blake et al., 2020). The inherent nature of contributory science is thus a reflection of the societal disparities that existed long before contributory science projects were established (Boakes et al., 2010; Courter et al., 2013). Though there has been a growing acknowledgement of these disparities, a framework articulating how biases arise in reported data remains outstanding.

Here, we articulate how social and ecological factors lead to biases in contributory science data. When discussing bias throughout this article, we are addressing two forms of bias—spatial bias in reported data and *unconscious bias* in participants (see Box 1) within contributory projects. We first present a conceptual framework illustrating how a combination of social and ecological factors can structure the spatial distribution and content of contributory data—focusing on contributory datasets such as iNaturalist and eBird. We then use this framework to demonstrate how social and ecological factors create biases in iNaturalist and eBird data in St. Louis, Missouri, the United States. We then briefly discuss the potential societal consequences of biases in these data. Lastly, we conclude by putting forth several recommendations that researchers and institutions may implement to ameliorate the biases in contributory data.

2 | A FRAMEWORK FOR UNDERSTANDING HOW BIAS IN CONTRIBUTORY DATA EMERGES

Just as landscapes are influenced by myriad social and ecological variables (e.g. Des Roches et al., 2021; Liu et al., 2007), contributory data are similarly influenced by a series of both social and ecological

BOX 1 Terms and definitions

Bias: An uneven or disproportionate representation of a particular subject or variable within the larger group. There are several types of bias, including spatial bias and unconscious bias (see definitions below).

Community: A group of individuals who have a stake in the local social, political, cultural or ecological environment.

Contributory science: A type of participatory science that decentralizes data collection by engaging individual participants to autonomously submit data with or without specific protocols provided by project leaders.

Diversity: Differences among individuals that may be based on (but not limited to) gender, race/ethnicity, income, sexuality, national origin, culture or religion.

Equity: Fairness and justice with respect to accessing resources, institutions and/or opportunities in response to current and historical disparities.

Inclusion: Intentionally created power structures, designs and processes where individuals with identities that have been historically and systematically excluded feel safe, welcomed, supported, valued and respected to participate in a project as their authentic selves, that is, present with all identities they hold (Cooper et al., 2023).

Justice: Dismantling barriers to opportunities and providing long-term, sustainable solutions so that all individuals and communities have the opportunity to participate.

Large-scale: Participatory science projects that transcend one place or community.

Participant: An individual—either a visitor or a member of the local community—who shares data with an organization, project or research institution.

Participatory science: An umbrella term that describes the data collected by participants.

Professional scientist: A person with traditional scientific training, including academic, museum, non-government and government scientists.

Spatial bias: Differences in the amount of data collected within a geographical area due to variables such as urbanization, accessibility and demographics, resulting in skewed data where certain regions are over-represented and others are underrepresented.

Unconscious bias: An inclination for or against particular people, places or things, which can be underpinned by factors such as experiences, socioeconomic status, race, ethnicity, nationality or gender.

filters (Figure 1). Ecological and evolutionary processes determine the *actual species pool* in a given habitat (e.g. Arctic fauna are not found in the desert). In contributory data, the actual species pool is further constrained by a series of subsequent filters reflective of the aforementioned social patterns and processes, ultimately giving rise to a *reported species pool* (Figure 1).

First, a *participation filter*, which determines the spatial distribution of reports within a region, reflects who is reporting the data. The 'who' necessarily includes where they are located and the areas they have access to, with research showing observations cluster in areas with denser populations (i.e. cities) and areas with easier access (i.e. more roads) (Zhang, 2020). Hence, the uptake of contributory science platforms by observers is uneven across space and demography. Similarly, data collection can vary spatially with socio-demographic variables. For example, in the United States, Ireland and Great Britain, research has shown that areas of high socioeconomic status tend to be better sampled than areas of lower socio-economic status (e.g. Davis et al., 2019; Mac Domhnaill et al., 2020; Pateman et al., 2021; Perkins, 2020). At the landscape scale, place-based bias due to negative human histories (e.g. war, segregation and displacement) may also influence where data are spatially reported (Gadsden et al., 2023), leading to race-based spatial biases in the United States (Blake et al., 2020; Ellis-Soto et al., 2023; Estien et al., 2023; Mahmoudi et al., 2022). In parallel, the policy of particular contributory projects or databases, for instance the Global Biodiversity Information Facility (GBIF), may lead to some species-rich countries to be undersampled compared with species-poor areas (Beck et al., 2013; Yesson et al., 2007).

Second, a *detectability filter* further narrows the pool to more easily observed species, thereby excluding many nocturnal, cryptic, timid or microscopic organisms. Aquatic organisms—especially fish, amphibians, aquatic plants and invertebrates—are particularly under-documented in contributory science databases (iNaturalist, 2022; Theobald et al., 2015). Lower representation of certain species may not only be due to their lower detectability but also the challenges associated with photographing organisms inhabiting dark, aquatic, subterranean or inaccessible (e.g. tree top and underwater) habitats (Aristeidou et al., 2021). This leads to more observations of organisms that are accessible and easy to photograph, regardless of the difficulty in identifying the species (e.g. lichen; McMullin & Allen, 2022).

Third, a *sampling filter* imposes finer-scale spatial biases, reflecting the fact that people are more likely to log observations in certain

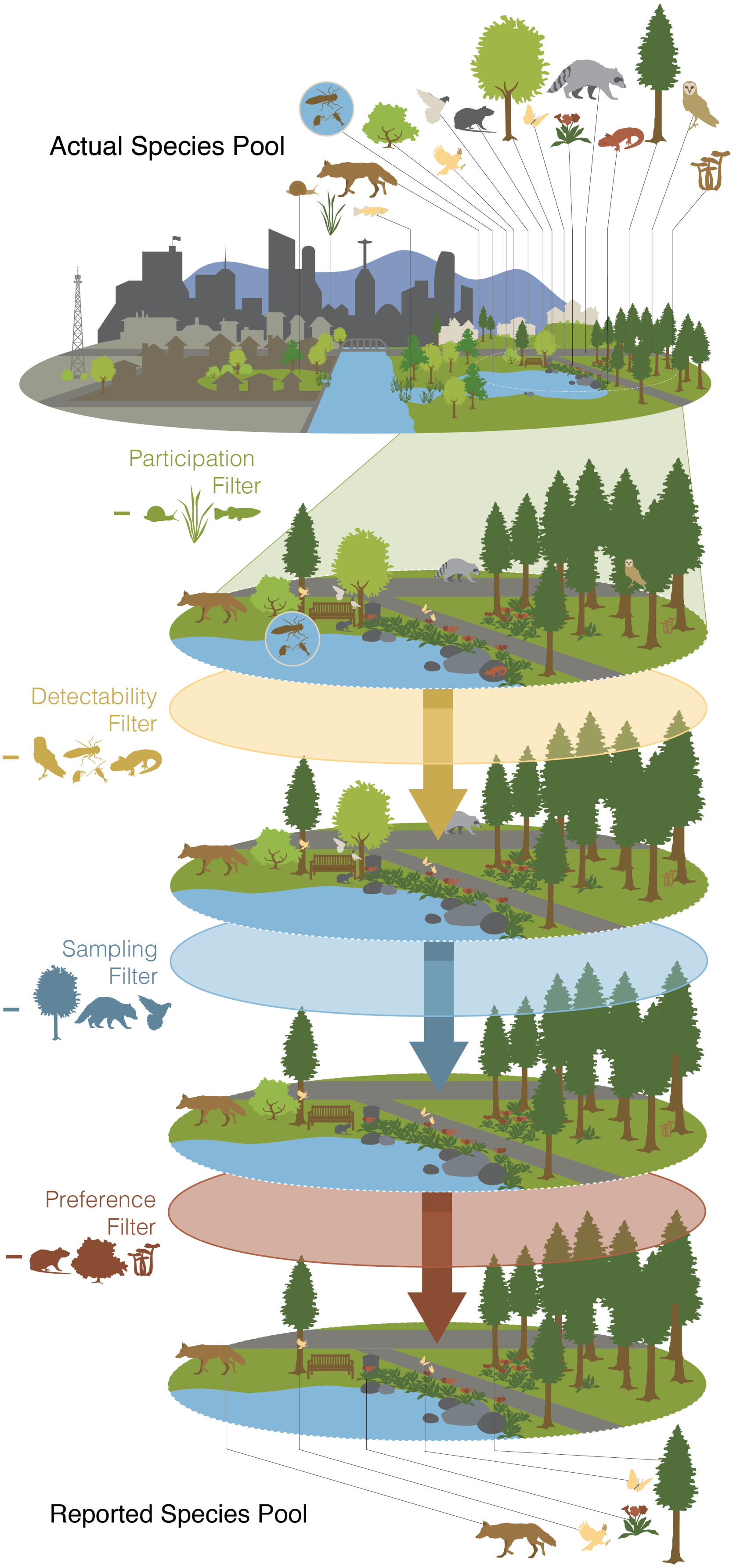

FIGURE 1 Social biases filter the species pool into a participant-reported species pool. For example, although the species available on a landscape may be vast (e.g. within a metropolitan area), this pool is immediately filtered by who is participating and where they have access to (*participation filter*). Following this, species' biology and behaviour impact their detectability with nocturnal, timid and cryptic species being harder to observe (*detection filter*). People participating in contributory science may be more willing to sample in green spaces while recreating than in grey spaces while commuting (*sampling filter*). Finally, public preference filters out pest, nuisance, uncharismatic or 'boring' species (*preference filter*). The order of these filters is not mutually exclusive, but the end result is a less diverse, publicly reported pool of species that is skewed due to social-ecological biases that inhibit the collection of all species.

circumstances—for example, when recreating in green spaces or alongside a trail/road versus commuting through grey spaces (Lopez et al., 2020), or choosing where to sample based on proximity to home (Thompson et al., 2023). This sampling preference for greenspaces creates additional spatial biases globally, with wealthier areas typically having more greenspaces (Chen et al., 2022; Rigolon et al., 2018). Additionally, finer-scale temporal biases occur due to individual preferences to sample at particular times of day or days of the week (Arazy & Malkinson, 2021; Cooper, 2014; Courter et al., 2013; Neyens et al., 2019).

Fourth, a *preference filter* modifies the pool in favour of charismatic, flowering, rare and colourful species (Stoudt et al., 2022) and against nuisance or 'boring' species. However, what may be considered 'charismatic' or a 'nuisance' can be regionally bound, culturally specific and vary by the individual observing the species (Belaire et al., 2015; Havinga et al., 2023). For instance, black rats (*Rattus rattus*) are considered pests in much of the world but are viewed as reincarnated kin to the Charan community at the Karni Mata temple in India (Trembley, 2023).

The four filters presented here—*participation*, *detection*, *sampling* and *preference*—broadly reflect the landscape's current and historical social and ecological dynamics, as well as human behaviour and activity. Importantly, these filters may interact and compound one another; thus, the order presented here does not reflect the relative importance of these filters, which cumulatively leads to discrepancies between the *reported species pool* and the *actual species pool*. Rather, the presented order helps illustrate that the *reported species pool* in contributory datasets is the synergistic result of social-ecological variables that ultimately produce 'spatial bias' (Figure 1; Box 1).

3 | APPLYING THE FRAMEWORK: A CASE STUDY IN THE UNITED STATES

Injustices (e.g. political disempowerment and segregation), inequities (e.g. economic disparity and educational access) and ecosystems vary regionally as a result of political history, culture, current and historical landscape use, and biotic and abiotic variables (Baldwin & Erickson, 2020; Cushing et al., 2015; Des Roches et al., 2021; Füssel, 2010; Gadsden et al., 2023; United Nations, 1965) To illustrate how social-ecological variables can influence the data reported to contributory projects, we focus on a city in the United States—St. Louis, Missouri.

Given our positionality as Western scientists concentrated in the United States (see Positionality Statement in Supporting Information S1), we decided to base our case study on the country in which we currently reside, work and have first-hand experience. The United States is a model for examining how societal inequity influences contributory data, given its extensive history and ongoing practices of racist and classist policies rooted in white supremacy, which shape the ecology of cities and their inhabitants (Agénor et al., 2021; Bonilla-Silva, 2006; Bullard, 2020; Cushing et al., 2015; Gadsden et al., 2023; Jesdale et al., 2013; Joseph-Salisbury & Connelly, 2018; Lavalley & Johnson, 2022; Lett et al., 2021; Mascarenhas et al., 2021; Morello-Frosch et al., 2011; Pulido, 2015, 2016, 2018; Schell, Dyson, et al., 2020; Smith et al., 2020; Swope et al., 2022; Wright, 2021). Moreover, the history of the United States as a land of immigrants founded on stolen land and built by stolen enslaved peoples has left lasting legacies on land, people and society (Cushing et al., 2015; Gadsden et al., 2023; Morello-Frosch et al., 2011; Norgaard & Reed, 2017; Pulido, 2016; Schell, Dyson, et al., 2020; Swope et al., 2022). Consequently, the United States illustrates how social-ecological variables interact to produce biases in contributory data.

3.1 | Case study: St. Louis, Missouri

St. Louis is located along the Mississippi River in the central United States and was historically dominated by prairie and open forest. The region was home to the Mississippian culture and the Cahokia people who lived on, tended to and modified the land from approximately 900–1500 CE. Due to European colonization in the mid-18th century, multiple species have been introduced to the region, including domestic pigeons (*Columba livia*) and Eurasian tree sparrows (*Passer montanus*) (Cornell Lab of Ornithology, 2023; Schorger, 1952), which contribute to the *actual species pool*. Currently, canopy cover and green space (Figure 2) are relatively homogenous throughout the city—providing a viable natural habitat for species in this area. Moreover, the human population density is relatively even throughout the city, meaning no region is vastly more populated (Figure 2). Notably, St. Louis is highly segregated along a north–south axis, with poor, Black communities in the north and wealthy, white communities in the south (Benton, 2018; Trivers & Rosenthal, 2015). As a result of segregation, environmental conditions vary, with more vacant properties, pollution, and illegal trash dumping in the northern, Black portion of the city (Interdisciplinary Environmental Clinic, 2019).

In St. Louis, eBird and iNaturalist observations are concentrated in the southern part of the city, where more white people live (Figure 2). Thus, the *participation filter* (Figure 1) is evident, with fewer observations coming from the north portion of the city, despite wildlife presence in the area (e.g. Burr et al., 2016; Mallinak, 2019; Moreno, 2018). Uneven participation in St. Louis is likely a consequence of variables, such as race, income and/or contemporary politics, which differ between the northern and southern parts of the city (Benton, 2018; Trivers & Rosenthal, 2015). Particularly, the legacy of land-use policies, specifically racial segregation, may be driving where data are spatially reported in St. Louis. After the influence of sociodemographic variables on participation, *detectability*, *sampling* and *preference* also influence reporting (Figure 1). For example, salamanders, a cryptic taxa that often hide under rocks and logs, have only three reported observations in St. Louis on the iNaturalist platform (*detectability filter*; Figure 1) (iNaturalist, 2022). Clusters of observations throughout the city correspond with Forest Park, the Missouri Botanical Garden, Tower Grove Park and the Gateway Arch National Park (Figure 2; Supporting Information S3), which are large, well-maintained public parks with many amenities. Such spatial clustering within certain

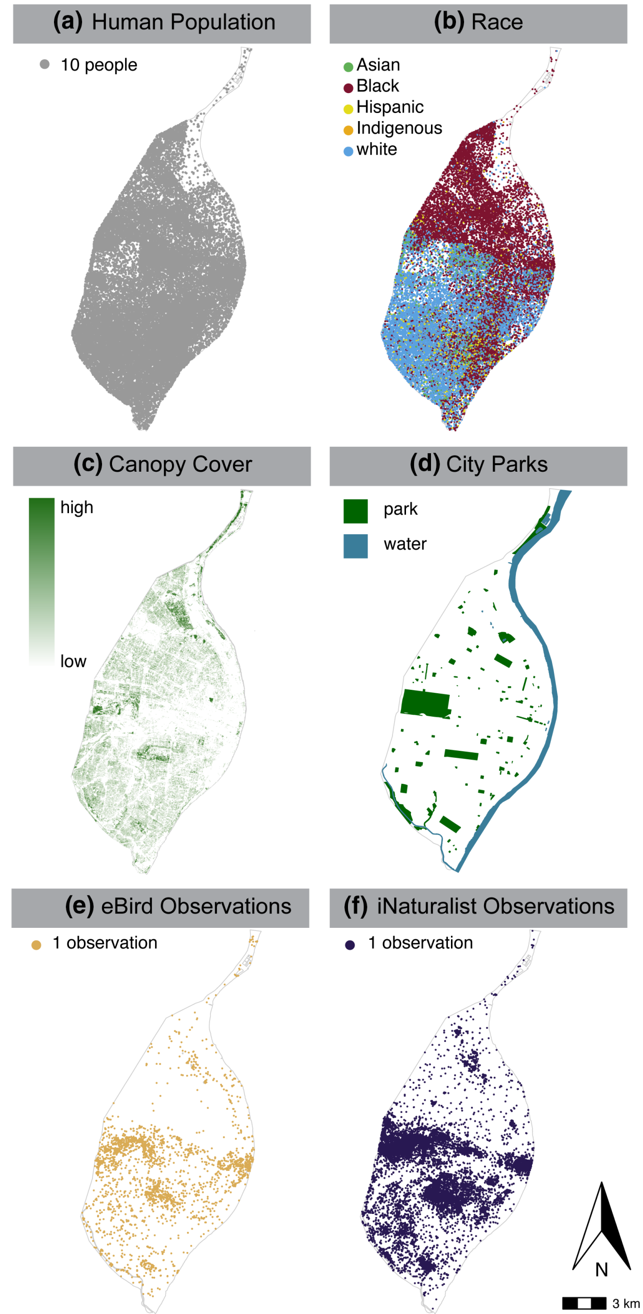

FIGURE 2 Spatial bias in contributory science data in St. Louis. Maps of St. Louis, Missouri, showing (a) human population, (b) self-reported race from the 2020 Census, (c) canopy cover, (d) location of city parks and waterways, (e) eBird observations and (f) iNaturalist observations. eBird and iNaturalist observations (e–f) are clustered around the major parks (d) and in the southern (predominantly white) part of St. Louis (c). See Supporting Information S2 for details about how these maps were created.

parks may arise due to an increase in people's willingness and desire to make observations while in recreational areas and because organizations leverage outreach events such as BioBlitz to encourage and teach participants to sample in green spaces (Lopez et al., 2020; National Geographic Society, 2022) (*sampling filter*; Figure 1). Lastly, individual preferences also influence reports in St. Louis. For example, feral pigeons (*Columba livia*), a ubiquitous species in cities, have 22,000 fewer observations than the Northern cardinal (*Cardinalis cardinalis*), a more colourful but also common urban bird in St. Louis (eBird, 2022) (*preference filter*; Figure 1).

Ultimately, the variables shaping the *actual species pool* in St. Louis are distorted by various social-ecological variables, yielding a biased *reported species pool*. Further research in St. Louis is needed to examine how social and political variables such as wildlife perceptions, inequity in investment, historical policies (e.g. segregation and zoning laws) and gentrification influence how observations are reported to contributory science platforms.

4 | SOCIETAL CONSEQUENCES OF BIAS IN CONTRIBUTORY SCIENCE DATA

Uneven data collection in participant-reported data creates sampling gaps, leading to misunderstandings of species distributions and undermining science's impact on society. For example, digital applications such as eBird and iNaturalist are used to understand species demographics and range expansion (Chardon et al., 2015; Rosenberg et al., 2019) and to track the presence of non-native species to inform wildlife management (e.g. Finley et al., 2023). Similarly, the Xerces Society for Invertebrate Conservation leverages contributory data to understand the spatial distribution and presence of pollinators and advocate for adding species under the Endangered Species Act (Xerces.org). However, societal inequities can interrupt the data reported and model predictions when species occur in areas where people are not recording observations (Figure 1). Notably, when uneven participation is due to a structural or systemic lack of access to the Internet, cell phones and time to participate in contributory science platforms (Chen & Wellman, 2004; Kalenkoski et al., 2011; Maitland, 2018; Reddick et al., 2020), simply showing participants how to use the platform is not enough to overcome this bias in data collection. In these instances, projects should work within these existing inequities (e.g. paper forms) to yield richer data for understanding biodiversity.

Biased datasets can also have ramifications for the broader community if leveraged for ecological management and decision-making, even for nonparticipants. Scientists have put forth models of biodiversity that heavily rely on contributory science datasets (Li et al., 2019), and if government officials use these models to designate priority areas for conservation, restoration or recreation funds based on biodiversity or what is understood as park usage (Robinson et al., 2018; Schuttler et al., 2019), then funds are likely to be allocated in ways that perpetuate inequities. For example, in St. Louis, data from eBird and iNaturalist suggest higher levels of biodiversity in the southern half of the city (Figure 2); this pattern could also be interpreted as higher usage of southern green spaces relative to northern ones. Data may suggest that resources, including park employees and city funds, would serve more people and wildlife if used to maintain the quality of the greenspace in the south compared with the north side of the city, as observed in Illinois with stream monitoring and eligibility for remediation funds (Blake et al., 2020). However, residents in the north part of St. Louis are encountering wildlife (Burr et al., 2016; Lane-deGraaf, 2019; Mallinak, 2019; Moreno, 2018), but it remains unreported. Hence, the spatial biases in contributory projects could have far-reaching consequences beyond the data and research product. Inclusion is critical for government officials and policymakers to make more just decisions to ensure community members fully receive the individual and communal benefits of contributory science initiatives (Loss et al., 2015).

Unfortunately, government officials and policymakers rarely publish their decision-making processes in academic journals, making it difficult to quantify how frequently contributory science data are directly used as evidence informing political decisions regarding conservation, restoration or funding allocations for green spaces or biodiversity (but see Finley et al., 2023; Haklay, 2015; Kieschnick, 2020; Nascimento et al., 2018; Sullivan et al., 2017). Importantly, we believe that the lack of publications showcasing the role of contributory science data in policy-making does not reflect the absence of this use but rather a disconnect between academics leveraging the data for peer-reviewed research and practitioners using the data for local-scale management (S. Kieschnick, pers. comm.). An important avenue for further research on this issue would involve exploring the literature associated with city council meetings, technical reports, government documents and similar mediums to quantify how commonly raw biodiversity data from contributory platforms is used in local decision-making (Cooper & Balakrishnan, 2013).

5 | MOVING TOWARDS A MORE INCLUSIVE FIELD

Despite over 75% of the human population and the majority of global biodiversity being concentrated in the Global South (Ceballos & Ehrlich, 2009; Coops et al., 2018; Donald et al., 2019; Keil & Chase, 2019; Population Reference Bureau, 2020), contributory science is dominated by the research priorities of the Global North due to colonial histories (Brulon Soares, 2021; Pettorelli et al., 2021; Trisos et al., 2021). Thus, regional disparities are evident in global science databases. For example, as of July 2023, the Global Biodiversity Information Facility (GBIF) shows a disparity with ~77,000,000 records for South America and ~981,000,000 records for North America. Hence, *professional scientists* in nations in the Global North (specifically the United States, Canada, Australia and Western Europe) should be keen to empower scientists in the Global South to collect and store data in ways that they see fit rather than through methods that are dictated by the Global North (Economou-Garcia, 2022; Pettorelli et al., 2021; Rodrigues, 2021; Trisos et al., 2021). Contributory projects—like eBird and iNaturalist—can increase equity by creating coalitions that include shared governance of projects by people from the Global North and South (Cooper et al., 2023). This is crucial not only because scientists in the Global North have historically colonized and profited from the biodiversity in the Global South (Bernstein, 2000; Dados & Connell, 2012; McMichael & Weber, 2020; Quijano, 2008) but because these data likely come with nuances best understood and interpreted by local scientists (Ocampo-Ariza et al., 2023; Trisos et al., 2021).

While there are some methods to reduce the amount of bias in volunteer-collected data, decolonizing and restructuring science is necessary to move towards a more just, equitable, and inclusive practice of data collection and curation. In some cases, statistical models help control for unevenly reported data (Kellner & Swihart, 2014; Rapacciuolo et al., 2021), but the outputs do not consider the complexity of human social variables that create biases in these datasets (Figure 1). In other cases, platforms attempt to control for bias in reported data by prioritizing presence/absence data and accounting for detectability by classifying participants by skill (Sullivan et al., 2009). However, we must reach for better solutions. We must be intentional in our attempt to ameliorate these biases, not only to statistically account for them but also to yield more accurate data and better support the communities where data collection occurs (Pandya, 2012). This includes recognizing that (a) science as an institution is deeply entrenched in a history of colonialism and white supremacy and does not centre nor empower community members, and (b) academic culture promotes individualism over community-based work while devaluing non-professional scientists and uncoupling science from the community it takes place in (Ahmad-Gawel et al., 2021; Bagilhole & Goode, 2001; Estien et al., 2022; Harding, 2006; Jones & Okun, 2001; McLean, 2013; Mohammed et al., 2022; Schell, Guy, et al., 2020; Trisos et al., 2021; Tuck & Wayne Yang, 2021).

We believe contributory projects can learn from co-produced and collaborative projects, which better engage the public, democratize science and improve community livelihoods. Thus, we put forth three recommendations to guide all scientists who are involved in contributory science projects: (1) centre science as communal and scientists as public servants, (2) prioritize individual and large-scale inclusivity, and (3) restructure institutional priorities and values.

5.1 | Centre science as communal and scientists as public servants

Science is a communal and collaborative field, and scientists should implement communication practices that ensure an equitable exchange of knowledge (Balestrini et al., 2017; Dobos & Jenei, 2013; Williams et al., 2021). This is especially true for scientists working for public institutions or receiving federal/public funding for research. As we discuss the outcomes of data collection through contributory research, it is integral to contextualize the involvement of scientists in community engagement and refrain from viewing the public as primarily a means to collect data. Rather, scientists should aspire to engage in contributory science projects both *with* and *for* the benefit of community members (Balestrini et al., 2017). This requires scientists to discuss the relevancy and outcomes of collected data and its significance for a particular community at various levels (e.g. neighbourhood associations and town halls). Furthermore, striving to include diverse community members in these efforts requires that we acknowledge that minoritized communities are working to survive capitalism, with little to no financial incentive to volunteer their time for a project that does not financially acknowledge their contributions. Hence, if we are to legitimately transform how we perform participant-based data collection, compensation will become a critical piece to bolstering engagement. Uniting scholarship and community members is critical to better-connecting science with the public, especially where research institutions are perceived as an impersonal collective within society.

5.2 | Prioritize individual and large-scale inclusivity

Most large-scale participatory science projects are contributory, where a scientist or organization has created a project that requires broad data collection, and participants contribute data towards this effort. In this project design, project volunteers may never interact directly with project scientists. However, there are ways to make contributory projects more inclusive. Basic steps include considering cultural relevance (e.g. creating appropriate project goals and methods based on community values) when designing the project and translating project materials into multiple languages. Contributory projects can become more collaborative by incorporating participants into more stages of the scientific process (Pandya, 2012). To do so, lead scientists should select or design protocols that best suit the community they are collaborating with. Rigid, lengthy procedures for data collection may create barriers for communities historically excluded from the sciences, functionally narrowing participation to those who have the time and already feel comfortable doing science (Fischer et al., 2021). Next, data and conclusions drawn from contributory projects should be made publicly available, communicated in accessible formats (not just scientific manuscripts) and made relevant to participants and community members. For example, the *Shutterbee Citizen Science Program* promotes planting native vegetation and trains participants in photographing and identifying bees while engaging with local community knowledge via newsletters, seminars and social media posts. Finally, while not the focus of this piece, contributory projects can also incorporate diverse expertise and information beyond Western scientific data, particularly local and Indigenous knowledge (Pandya, 2012; Senabre Hidalgo et al., 2021; Tengö et al., 2021), which could greatly improve project outcomes (e.g. Hessami et al., 2021; Lamb et al., 2023; Martinez et al., 2023; Moore & Kumble, 2023). We acknowledge that this particular approach requires tremendous work, and describing it further is out of the scope of this paper (but see Corburn, 2003; McOmber et al., 2022; Tengö et al., 2021; Tripathi & Bhattarya, 2004).

Contributory science projects that focus research on local, tangible issues relevant to community members are more likely to be appealing to local residents and foster participation (Pandya, 2012; Rotman et al., 2012, 2014; Vohland et al., 2021; West & Pateman, 2016). However, localized priorities present challenges for large-scale projects amalgamating data across regions. Scientists and large-scale platforms, such as eBird and iNaturalist, can make efforts to design projects that promote and support local leadership and allow for regional customization (e.g. The City Nature Challenge, which takes on a 'train the trainers' model, utilizing iNaturalist; Tupikina et al., 2021). For existing large-scale projects, lead scientists can work to understand participants' identities, priorities and interests while weaving in their knowledge, which can lead to better long-term participation (Rotman et al., 2014). This is critical for achieving more just outcomes because when participants are better understood, scientists can actively 'centre the margins' by reassessing project promotion, protocols and research agendas to be more relevant to the community (Hall, 1992; Langhans et al., 2023). For example, *SuperProject*, through The Natural History Museum of Los Angeles County, is designed to address gaps in iNaturalist data in Los Angeles County by focusing on and partnering with participants in particular regions (e.g. the San Diego Natural History Museum's *Healthy Canyons Project*) (Pauly et al., 2020).

5.3 | Restructure institutional priorities and values

Research institutions, including academia, have traditionally been antithetical to community-centred science practices and research. Although this is changing (Esmail et al., 2023), the formal education of natural scientists often does not include training on how to engage with local communities at any scale or even how to collaborate with organizations that work with communities (Leshner, 2007). Instead, our education defines success as the rapid gathering, analysis and publication of results in academic journals, which are rarely accessible to the public. This structure not only incentivizes non-collaborative work but also actively depreciates involvement with the community where the work is being conducted. The pressure of the 'publish or perish' environment within academia, along with a lack of formal training on how to collaborate with the public, makes community engagement difficult for many researchers. Researchers who wish to engage communities in their work often experience a lack of support from their institutions. These researchers must commit to the extra work of overcoming antiquated institutional barriers and self-educate on community collaboration. Additionally, for academic researchers, the timeline to apply for tenure, typically in Years 5 or 6 as an assistant professor, does not accommodate the time it takes to build relationships with communities before beginning a research project and working towards publication. However, we believe it is essential for faculty to take on this work since students and postdoctoral researchers move frequently, and building community relationships requires a large investment of time and resources.

Contributory projects are often run by white-dominated institutions with a volunteer framework, and the lack of *diversity* in participation is an indication that these projects perpetuate social inequities present in our society. Thus, the success of contributory science is tied to broad-scale commitments to diversity, *equity*, *inclusion* and *justice* to create projects that do not use people as tools for science but shift projects to be useful to people. Moreover, this commitment includes shifting research goals and questions such that volunteering is not viewed as a tool for science but centres science as a tool for people.

We offer a non-exhaustive list of recommendations that institutions—including departments and universities—can undertake to commit to a more inclusive field: (1) universities can provide classes on community engagement and encouraging translational research (Zourou & Tseliou, 2020); (2) institutions providing funding should expand what is considered fundable research questions to better align with priorities and interests in non-dominant cultures; (3) incentivize and provide opportunities for students, staff, and faculty to engage with contributory data and communities through grants (Estien et al., 2022); (4) create and fund faculty and staff positions that involve communities and contributory research; (5) offer more financial support, especially for graduate students and early-career professional scientists, to encourage translational research and open access publication; (6) restructure tenure and promotion evaluations such that higher value is placed on non-traditional markers of academic success like collaborating with community members, conducting outreach and mentoring (Boyer, 1997; Esposito et al., 2022; Swope et al., 2022) and (7) *actively* move towards decolonizing academia (Eizadirad, 2019; Rodríguez, 2018; Tuck & Wayne Yang, 2021), which will involve greatly restructuring what academic institutions value and shifting the goals of research. We emphasize that these recommendations are not an easy checklist and highlight that in order to move forward, institutions must change.

6 | CONCLUSION

Although research has previously described the spatial bias of contributory data (Beck et al., 2014; Di Cecco et al., 2021; Zizka et al., 2021), less attention has been given to how these biases arise as a result of both social and ecological variables. In this article, we acknowledge the complexity of what is considered bias, contextualize what is ultimately considered spatial bias and describe how both social and ecological mechanisms can influence data reported to contributory projects (e.g. eBird, iNaturalist). Our framework is crucial to prevent fundamental misunderstandings of inequity in data reported, what may drive it and how it may be remedied. Given the complexity of spatial bias, especially in social-ecological systems such as cities, we must reflect on and examine *what* data are collected, *why* those data are collected, and *for whom* and *what purpose* the data serve. This reflection, along with a social-ecological understanding of how biases in data arise (Figure 1), is necessary to understand how to effectively improve equity in contributory data—both its collection and dissemination. Addressing the inequities in contributory data will require justice-oriented work within institutions and projects to shift research priorities and goals to ultimately uplift communities.

Our recommendations are not an exhaustive list of what is needed to dismantle an institution that traditionally values data output over people and community. Rather, we intend to present a first step for more equitable and just research practices in the sciences. As an authorship team, we place incredible value on the contributions of our local communities—including contributory scientists—to science. We envision a future landscape of science that values and empowers the communities that show interest in science on various levels, including those who directly participate in data collection.

AUTHOR CONTRIBUTIONS

Elizabeth J. Carlen, Cesar O. Estien, Tal Caspi, Deja Perkins, Simone Des Roches, Rebecca F. Johnson and Alison N. Young conceived the manuscript. All authors contributed to writing and editing the manuscript.

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The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

There are no data associated with this manuscript. Information regarding how maps were made using R can be found in the supplemental materials.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supporting Information S1: Positionality statement.

Supporting Information S2: Methods for creating maps.

Supporting Information S3: Map of St. Louis Parks.

Supporting Information S4: Literature cited in supplemental material.

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