CITIZEN SCIENCE FOR FUTURE GENERATIONS

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CITIZEN SCIENCE FOR FUTURE GENERATIONS

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Editorial: Citizen Science for Future Generations

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Editorial on the Research Topic

Citizen Science for Future Generations

Schooling is a concept that is as ancient as human history. Initially, offspring learnt to survive and subsist from their parents and immediate families/tribe. Later in history, with the evolvement of agricultural societies, they learnt trades. Eventually, with the industrial revolution in the mid-19th century that required concentrated man-power and children's rights evolved (cf. Dickens, 1838), the concept of central schooling was invented. However, while the education within family groups remains similar between generations, the schooling system attempted to evolve into a modernized version that attempted to keep up with technological development and increasing, cumulative knowledge of the human society. The concept behind it being that the children should be able to meet the needs and expectations of the future when they become adults (Targamadze, 2019). This attempt to keep up with modernization over the past three centuries has resulted in varying results, especially in countries with poor economies or depressed by other communities (e.g., colonialism, economic exploitation; Woolford, 2013). In recent decades, environmental awareness has led to changes in the curriculum taught in schools and is evolving with different methodologies. One of the most recent of these methods that has developed is Citizen Science (cf. Strasser et al., 2019).

Strasser et al. (2019) made the distinction between "amateur naturalists" of the past two centuries where people of different professions, for whom their scientific occupation was a "hobby," was mostly unpaid, and hence before the mid-19th century was mostly conducted by "citizen science" (see also Haklay, 2013). Since the introduction of modern Citizen Science techniques, there are several descriptions which show how it has also diversified almost instantaneously ranging from "science that serves the citizens" (Irwin, 1995) to "science performed by the citizens", i.e., science performed for the people, by the people (Strasser et al., 2019). However, today it is mainly conceptualized as allowing citizens to contribute to ongoing scientific research, whether with (eBird, 2002) or without their knowledge by taking advantage of a range of public-media platforms (Mikula, 2015; Dylewski et al., 2017). Bonney et al. (2016) presented a typology of how Citizen Science projects could be characterized: (1) contributory projects wherein scientists design the experiment and citizens contribute data (e.g., North America Christmas Bird Count); (2) collaborative projects wherein the public can also voice opinions and contribute to project design, help analyze the data, and even disseminate the findings; or (3) co-created projects wherein public participants are involved in the whole process of developing and implementing the scientific process.

A wide range of projects have developed over time wherein innovative scientists have successfully incorporated citizens into their data-collection process. An example of a globally active project is eBird by the Cornell Lab of Ornithology wherein the public share their field observations, and which allows scientists to mine for their relevant projects (e.g., Callaghan et al., 2020, 2021). There are many such projects in almost every field of interdisciplinary sciences and

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ranges from astronomy (Galaxy Zoo) through medicine (PatientsLikeMe), to the environment (Penguin Watch). Also, an increasing number of professional networks for Citizen Science have been founded (US-based Citizen Science Association, European Citizen Science Association, Australian Citizen Science Association, Israel's Taking Citizen Science to Schools).

In order to pull these efforts together, and to try and understand how and what efforts are made, to better equip the next generations to be good Citizen Scientists. A total of 11 papers have been included in this special issue about "Perspectives in education and Citizen Science in the next generations." We hope that the projects included will serve as examples of how the upcoming generation can be primed as potential help for gathering large quantities of data with minimal investment of time and effort.

Citizen Science has been applied to a wide range of issues including beaches (Fanini et al.), biodiversity monitoring in the Red Sea (Meschini et al.), marine invasive species (Encarmacao et al.), True Hoppers (Kitteleberger et al.), avian ecology (Lefebvre, 2020) and recreational birdwatching (Randler), and the surveillance of Coastal Redwoods (*Sequoia sempervirens)* (Young et al).

Another example of how attitudes toward wildlife can be evaluated and influenced is that of Prokop et al. who wished to understand how they could make conservation more effective by improving human attitudes. The authors investigated whether animal posture influences human willingness to protect animals by manipulating animal postures and examined perceived cuteness, fear, and the willingness to protect them. Responses from 349 adults showed that bipedal posture increased cuteness, lowered fear, and increased willingness to protect, but this effect works specifically in the case of small species (e.g., a ground squirrel); and the opposite in larger species (e.g., a bear). Interestingly, the strongest positive effect of bipedalism was when the animal was not only small, but also phylogenetically closer to humans (i.e., a mammal is closer than an insect) and with direct eye contact. They concluded that bipedal posture in large-bodied species is perceived as threatening, because these animals look even bigger than they are and could be perceived dangerous.

All said many of the projects included in this special issue involve adults. It is only in recent years that scientists are exploring the possibilities of school children conducting scientific projects (Schleicher and Schmidt, 2020). This came at a very opportune moment because many of the schools had reached a point of knowledge-satiation (eutrophication; Targamadze, 2019) and was casting about for ways in which to involve students in projects and to arouse their interest in the mundane process of school learning. The education systems started incorporating environmental studies under the umbrella of the sciences. Hence, the introduction of Citizen Science projects came at a very opportune time and was readily accepted by the system (Sheard et al., 2020). Sandén et al., demonstrate how the Tea Bag Index App facilitated the inclusion of a subject neglected by schools—-soil science and its connection to climate change. Together with the schools, they collected important data pertaining to the carbon cycle, gave inspiration to the teachers, and awakened interest among the participating school students; and allowed them to collect data across Austria. In this manner the study makes a big contribution to the understanding of global patterns in the carbon cycle. Similarly, Spellman et al. emphasized to children the process of climate change and decision making through the evaluation of their ability to sustain berry resources for their communities.

However, not all experiments were successful, and the reactions of the scientists range from the skeptical (Castagneyrol et al., 2020; Rouviere and Ruxton, 2021), to those preaching to be careful (Schulwitz et al., 2018), and to those who feel that they are not fully realized (Cohn, 2008; Battisti et al., 2020; Callaghan et al., 2020). Castagneyrol et al. (2020), in the framework of an on-going project *Oak Bodyguards* applied existing standardized protocols to estimate predation rates on artificial caterpillars placed on low branches of oak trees, and insect herbivory on randomly collected fresh oak leaves. They found that although most of the schools estimated attack rates, none analyzed the herbivory part of the experiment. They concluded that the results obtained by schoolchildren were like that of untrained professionals, and that the raw data acquired by schoolchildren require several quality checks by professional scientists before they can be used. Although in general we agree with that said, we feel these results should be considered in a more nuanced manner as similarly to untrained professionals and were not equipped with the proper tools before being asked to collect the data. Also, the fineness/resolution of the data being collected should be taken into consideration. In their case, Castagneyrol et al. (2020) built upon an ongoing Citizen Science program and assessed the ability of schoolchildren to accurately estimate the strength of biotic interactions in terrestrial ecosystems. However, in this study no information was provided on the ages of the children involved in the study. We think this is very important because children mature with years and acquire greater manipulative and behavioral traits which are lacking in younger children (Yosef et al., 2021a). Hence, the age at which Citizen Science projects can be properly accomplished by school children is a factor of how well they have developed their behavioral, cognitive, and motoric capabilities (Norton et al., 2005), including their concentration and observational capabilities (McClelland et al., 2013). We also contend that the subject of how well they are trained prior to data collection influences subsequent data quality perceptions of complex ecosystems (Sheard et al., 2020; Gal et al., 2021).

However, it is of importance that the "baby not be thrown out with the water." Hence, although there are drawbacks to involving citizen science, especially with school children, Arazy and Malkinson emphasized the need for citizen science programs to collect data that allow for robust statistical analyses in order to effectively support evidence-based wildlife conservation and management. They think that integrating Citizen Science data with other, more traditionally collected datasets can improve population estimates and inferences. They illustrated their questionnaire's ability to capture the factors driving observer-based biases by employing data from a local project on the iNaturalist platform. Also using the iNaturalist mobile app, Young et al. provide the first explicit example of a Citizen Science project using a Translational Science Education (TSE) framework, which brings educators and researchers together to produce both actionable science and authentic learning experiences. By investigating urbanization in a coastal redwoods (*Sequoia sempervirens*) region of California, in collaboration with local students and educators, they show how a TSE-based citizen science project can result in both learning and data generation. Qualitative reports by educators showcase the power of TSE approaches to engage students and teach environmental stewardship practices. Their case study provides insights that can inform the development and structure of future TSE efforts, while highlighting the ability of the TSE framework to connect and benefit students and researchers during citizen science projects. Further, Sun et al. with a citizen science program called iSeeMammals developed in New York state in 2017 to supplement costly systematic spatial capture-recapture sampling by collecting opportunistic data from one-off observations, hikers, and camera traps. The triumvirate of increased spatial and temporal coverage by at least 2-fold compared to systematic sampling, an 83% reduction in annual sampling costs, and improved density estimates of the American black bear (*Ursus americanus*) when integrated with systematic data highlight the benefits of collecting presence-absence data in citizen science programs for estimating population patterns.

In our efforts to equip the next generation with the proper tools for scientific thought and decision-making, we are involved for the past decade in teaching scientific research at a high school in southern Israel (e.g., Yosef et al., 2020). In the framework of the Israeli Ministry of Education we recruit school children between the ages of 15 and 17 years old to engage in a yearlong scientific project wherein they are taught scientific thought, techniques and then do several months of field work (minimum 60 h of field observations) and write up a thesis and given course credit for the final certificate (cf. Yosef et al., 2021a). The scientific projects are also recognized by academic institutions of higher education and these students are given bonus points when they register and are an incentive for many of the students. Over the past 10 years we have worked with 183 students who chose to be involved in research over and above all their regular school requirements. We did not include the data for 2020–2021 because of the COVID-19 lockdowns which resulted in many abandoning their projects owing to lack of access to their project sites or laboratories. We divided their individual projects into coarse and fine projects. We considered coarse projects ($N = 113$) to be those wherein the children had to observe wild animals and their responses to various cues in the environment. The rest ($N = 70$) chose projects that were confined to laboratories/zoos/aquariums and were based on manipulations of experiment-specific parameters. All the students were tutored for 3-months prior to beginning their projects and we evaluated their progress. We discovered that children that worked in closed areas appeared to lose interest at some stage, were not punctual, and the drop-out was relatively high and only 68% ($N = 78$) submitted their thesis (Yosef et al., 2021a,b). In contrast, children that choose to work in the field were highly motivated and enthusiastic, adhered to the scientific protocol specified beforehand, were punctual at their observation posts, and took their project seriously resulting in 93% ($N = 105$) of them successfully submitting their thesis. Of the latter, owing to the high quality of their data, were also involved in scientific publications (e.g., Yosef et al., 2020, 2021b). We find that children who were well-prepared and rehearsed with the research techniques also performed well in the field during data collection. These results are like that found in the teabag experiments that were conducted worldwide (Keuskamp et al., 2013; Sandén et al.).

It is of interest to note that children, apparently more so than adults, are susceptible to fears and erroneous falsifications (Broomfield et al., 2002), especially when it comes to animals (Porot and Mandelbaum, 2021). Hence, it is of interest that Zvaríková et al. tried to elucidate what is so frightening and disgusting in spiders and that can result in arachnophobia in humans. They manipulated a real picture of a spider and enlarged its eyes, body hair, opistosoma (abdomen), chelicerae and legs and the series of photographs were rated by many people in Slovakia. They concluded that fear and disgust was triggered by enlarged chelicerae, abdomen, and the presence of body hair. In contrast, longer legs were associated with fear, but enlarged eyes were not. They conclude that people are afraid of enlarged animal weapons that are threatening. The enlarged abdomen resembled a big tick or a blood-sucking invertebrate and was considered disgusting. The study illustrated that to raise empathy amongst the laymen one should not use spiders with big abdomens and dense body hair as a flagship species.

In conclusion, we find that Citizen Science, whether pertaining to that collected randomly or systematically by adults, or in a structured, pre-planned manner by school children, can contribute to science but requires advance preparation and investment of time, energy, and resources. Yet, in spite of the drawbacks of the young age and inexperience of the high school children, we consider it pertinent to continue to educate them to become responsible citizens in their communities, to know how to plan and execute projects, and how to make result-based decisions especially as policymakers. We believe that if we equip the future generations with the correct tools at a younger age, we ensure the recruitment of responsible citizens into our communities in the future.

AUTHOR CONTRIBUTIONS

RY and PT: conceptualization, organization, correspondence, reviews, and final draft. RY: first draft. All authors contributed to the article and approved the submitted version.

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Citizen Science Data Collection for Integrated Wildlife Population Analyses

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Citizen science, or community science, has emerged as a cost-efficient method to collect data for wildlife monitoring. To inform research and conservation, citizen science sampling designs should collect data that match the robust statistical analyses needed to quantify species and population patterns. Further increasing the contributions of citizen science, integrating citizen science data with other datasets and datatypes can improve population estimates and expand the spatiotemporal extent of inference. We demonstrate these points with a citizen science program called iSeeMammals developed in New York state in 2017 to supplement costly systematic spatial capture-recapture sampling by collecting opportunistic data from one-off observations, hikes, and camera traps. iSeeMammals has initially focused on the growing population of American black bear (*Ursus americanus*), with integrated analysis of iSeeMammals camera trap data with systematic data for a region with a growing bear population. The triumvirate of increased spatial and temporal coverage by at least twofold compared to systematic sampling, an 83% reduction in annual sampling costs, and improved density estimates when integrated with systematic data highlight the benefits of collecting presence-absence data in citizen science programs for estimating population patterns. Additional opportunities will come from applying presence-only data, which are oftentimes more prevalent than presence-absence data, to integrated models. Patterns in data submission and filtering also emphasize the importance of iteratively evaluating patterns in engagement, usability, and accessibility, especially focusing on younger adult and teenage demographics, to improve data quality and quantity. We explore how the development and use of integrated models may be paired with citizen science project design in order to facilitate repeated use of datasets in standalone and integrated analyses for supporting wildlife monitoring and informing conservation.

Keywords: community science, integrated model, point process, presence-only, presence-absence, wildlife population, engagement, technology

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INTRODUCTION

A common objective of citizen science (i.e., community science) is to assist in scientific research by contributing data beyond the spatial and temporal capacities of professional researchers (Shirk et al., 2012). Facilitated by widespread internet access, ecological monitoring through citizen science is increasingly used to document and study wildlife populations across wide spatial distributions and timeframes (Bonney et al., 2009; Follett and Strezov, 2015). For example, iNaturalist has collected over 60 million biodiversity observations on all 7 continents, from over 3.5 million contributors since its start in 2008[1]; eBird has collected over 900 million bird observations from approximately 800,000 users since its start in 2002 (Sullivan et al., 2009). Citizen science has advanced our knowledge of wildlife patterns, including species distribution, phenology, and behavior (Dickinson et al., 2012; Fink et al., 2013; Soroye et al., 2018), and has even discovered new species (e.g., Amézquita et al., 2013). Importantly, in the age of rapid habitat change and biodiversity loss, citizen science can also support wildlife conservation and management. For example, citizen science has helped confer conservation status to at-risk species and identify hotspots of human-wildlife conflict (Dwyer et al., 2016). Management agencies have also long collected harvest data from hunters, a form of citizen science data, to estimate population trends (Gove et al., 2002), and have begun to request public assistance in monitoring wildlife health and species of concern (Burr et al., 2014; Dissanayake et al., 2019). To address biodiversity issues, from local to global, citizen science datasets should endeavor to meet the requirements of analyses that produce robust inferences for evidence-based action (Guillera-Arroita et al., 2015; Parrish et al., 2018).

A fundamental design consideration in citizen science programs is the type of data to collect. Data on species or individuals may include information only about detected presences (i.e., presence-only, PO data), or also information about sampling effort through absence/non-detections (i.e., presence-absence, PA data). The most common form of PO data is one-off observations, such as those submitted to iNaturalist, while examples of PA data include complete checklists of detected species (e.g., eBird; Johnston et al., 2020) and data from motion-triggered trail cameras (i.e., camera traps) when periods of camera operation are reported (e.g., McShea et al., 2015; Hsing et al., 2018). Information about sampling effort in PA data help model the data collection process and account for noise and variable quality (Isaac et al., 2014) that can occur due to variation in user expertise (Johnston et al., 2018), imperfect detection (MacKenzie et al., 2002), and spatial and temporal sampling biases (Courter et al., 2013; Geldmann et al., 2016). In contrast, PO data, which do not contain information absences or sampling effort, are limited to relative patterns of abundance and occurrence probabilities rather than absolute measures (Royle et al., 2012; Fithian et al., 2015) and are more prone to unreliable and biased inferences. Functionally, PA data also enable a broader range of analyses compared to PO data; PA data can be used in PO data analyses by removing absence information, but PO data cannot be used as-is in PA data analyses. As a result, many have cautioned against the collection of PO data and advocate instead for PA data collection for rigorous analyses and robust inferences about population size, distribution, and habitat use (Brotons et al., 2004; Isaac et al., 2014; Bayraktarov et al., 2019; Callaghan et al., 2019).

We expand on these recognized benefits of PA data in citizen science programs by highlighting their ability to improve ecological inferences when integrated with other datasets within a single statistical framework. While standalone analyses of citizen science data can yield robust inferences (Davies et al., 2012; Crum et al., 2017; Altwegg and Nichols, 2019), there is also growing interest in maximizing the value of citizen science data through joint analysis with other datasets that have partially overlapping information content (Zipkin and Saunders, 2018). Integrated models can improve parameter estimates, expand the spatial and/or temporal extents of inference, and even estimate latent parameters that were previously unidentifiable (Schaub and Abadi, 2010; Chandler and Clark, 2014; Robinson et al., 2018). Small or sparse datasets, such as in nascent citizen science programs, can both contribute to and benefit from integrated modeling approaches. In short, integrated analyses provide opportunities to synthesize new knowledge to support biodiversity research and conservation (Theobald et al., 2015; Miller et al., 2019).

Integrated models based on spatial point processes are of particular interest, because it is natural to understand and straightforward to model spatial encounter data on species or individuals as realizations (i.e., sampling/data collection process) of a spatial point process (i.e., population of individuals) (Royle et al., 2017; Kery and Royle, 2020) in a hierarchical framework. Spatially explicit encounter histories of individuals (i.e., spatial capture-recapture; SCR) are an ideal type of PA data to include in such integrated approaches because they are highly informative about the point process. Furthermore, each PA dataset can be modeled as arising from its own distinct sampling process that served its original citizen science program or sampling objective. Most integrated models have therefore focused on PA data, as incorporating PO data requires new model structure to either infer missing information about sampling effort based on other species (Fithian et al., 2015) or explain the PO data as a thinned point process (Dorazio, 2014). We therefore echo recommendations for citizen science programs that monitor wildlife for scientific purposes to collect PA datasets when possible, given the ease with which they can be incorporated into integrated models.

Citizen science data collection and submission should also be accessible and usable while in the pursuit of data. This serves the practical need to collect sufficient high quality data for analysis (Lasky et al., 2021) and upholds the democratic spirit and intention of citizen science (Mueller et al., 2012; Lynn et al., 2019). Accessibility refers to how easily contributors with different resources can participate (e.g., collect and submit data), while usability refers to the effectiveness, efficiency, and satisfaction of the user experience (Petrie and Kheir, 2007). Limited access to equipment and onerous protocols can deter participation (Newman et al., 2010). Indeed, more programs still collect PO data than PA data because the former are easier to collect (i.e., more accessible) (Pocock et al., 2017). Similarly, opportunistic sampling—in which data are collected upon encounter—may pose a lower barrier to access compared to systematic sampling—in which data are collected only under specific spatial and temporal conditions (Dennis et al., 2017; Bradter et al., 2018). Further declines in participation due to unfamiliar or inaccessible technologies, platforms, or poor user-interfaces (Newman et al.,

[1] inaturalist.org

2010), can be reduced through multiple submission platforms (e.g., computer, paper, and devices such as smartphones) to increase access and engagement with diverse participants. User-interfaces that build minimum data requirements into succinct workflows may also create positive and engaging experiences (Wald et al., 2016). The ability of citizen science programs to collect data for robust ecological inferences is influenced by interrelated decisions concerning data types and effective, user-centered protocols.

Here, we describe a citizen science program called iSeeMammals that was designed to collect opportunistic species-level data in New York state, United States. iSeeMammals enables members of the public to collect any of three types of data: PO data from one-off observations, PA data from hikes, and PA data from camera traps (**Figure 1**). iSeeMammals launched in 2017 and has focused initially on American black bears (*Ursus americanus*), with the objective of assessing how citizen science efforts could support integrated analyses to improve population abundance estimates. Exploring the feasibility and benefits of a citizen science approach was motivated by logistical and financial limitations of systematic sampling; New York is 141,300 km^2 but annual spatial capture-recapture data collection in June—August since 2015 had been restricted to approximately 241 locations in the southern part of the state (40,079 km^2) due to its high annual cost of approximately $192,000 USD. We describe the iSeeMammals data collection and submission process and report results from its first year of black bear monitoring. Finally, we reflect on the analytical and citizen science developments that can facilitate more opportunities for integrated models with citizen science data to meet research and conservation needs.

MATERIALS AND METHODS

We created iSeeMammals so members of the public could contribute data on black bears from one-off observations (PO data), hikes (PA data), and camera traps (PA data) toward statewide wildlife monitoring and research. We offered both PO and PA data options because both can be used in joint models and also to collect as much data as possible given the popularity of PO data in citizen science approaches. We considered hikes an accessible extension of PO data, similar to traveling counts in eBird. Camera traps are already familiar to and commonly used by many hunters, wildlife enthusiasts, and citizen science wildlife monitoring programs (McShea et al., 2015). Prior to launching, iSeeMammals outreach included social media communications (Twitter, Facebook, Instagram, radio, television), connecting with established organizations to share information with their members, meeting with local communities and interest groups, and attending outdoor and wildlife-related events. After launching, outreach continued through newsletters to participants, social media communication, trainings, and word-of-mouth.

The potential for iSeeMammals to serve as a long-term monitoring tool motivated the development of an internet-based portal for data submission, with multiple platforms to increase access. Data could be submitted through a website[2] and a free eponymous application (app) available in the Apple and Google app stores (Apple, Inc., Cupertino, CA, United States; Google, Inc., Mountain View, CA, United States) (**Figure 1**). We refer generally to contributors as participants, but specifically as users when in relation to the data submission platforms. An account with the iSeeMammals program was not necessary to submit data but was encouraged so that users could keep track of their submissions. The website and app included instructions for submission, tips and tricks for identifying signs of black bear presence, recommendations for how to set up a camera trap (height of camera, angle placement relative to the sun, local habitat, etc.), and additional training materials including images and quizzes. The app requested access to the user's (device) location and camera in order to collect GPS coordinates and photographs that were critical for data quality. Due to concerns raised by participants about private property and potentially sensitive locations, personally identifying information and raw GPS coordinates were used only for research purposes. A privacy policy communicated that publically shared results would be anonymized, and either spatially jittered or displayed at coarser aggregate scales.

Observations of black bears included detections of bears or bear signs (e.g., scat, track, hair, or markings). In a series of multiple choice questions on either the website or app, iSeeMammals required (1) the category of observation (bear, scat, track, hair, or markings), (2) verification of the time and GPS location of the observation based either automatically on the metadata of an included photograph or by manual entry, (3) confidence in identification (Could be anything; Might have been a bear; Probably was a bear; I'm positive this was a bear), and (4) number of people present for the observation (Just me; 2; 3; 4; or ≥5 people). Questions about confidence of species identification and party size were collected to potentially help quantify sampling effort. Users were encouraged to include a photograph of the observation to help confirm species identification. Users could also supply a text description. An observation by itself constituted a one-off observation and provided PO data, while observations submitted in association with a hike provided PA data (described below).

Hikes at minimum consisted of sequential, timestamped GPS coordinates. Users could submit hikes through the app and view hike submissions on both the app and website. At the start of a hike, the user would begin the hike function and provide a unique name for the hike. The app recorded GPS coordinates at approximately 500 m increments to prevent excessive battery drainage during long hikes. When a hike was complete, users would press a button to end the hike. iSeeMammals then required (1) confirmation of the general accuracy of the route based on a map outlining the hike route, (2) the number of people in the hiking party (Just me; 2; 3; 4; or ≥5 people), and (3) the likelihood of returning at a later date to repeat the hike (Not at all; Possibly; Most likely). Questions about party size and likelihood of return were, respectively, collected to potentially help quantify sampling effort and data quality through repeat visits. Lastly, the

[2] www.iseemammals.org

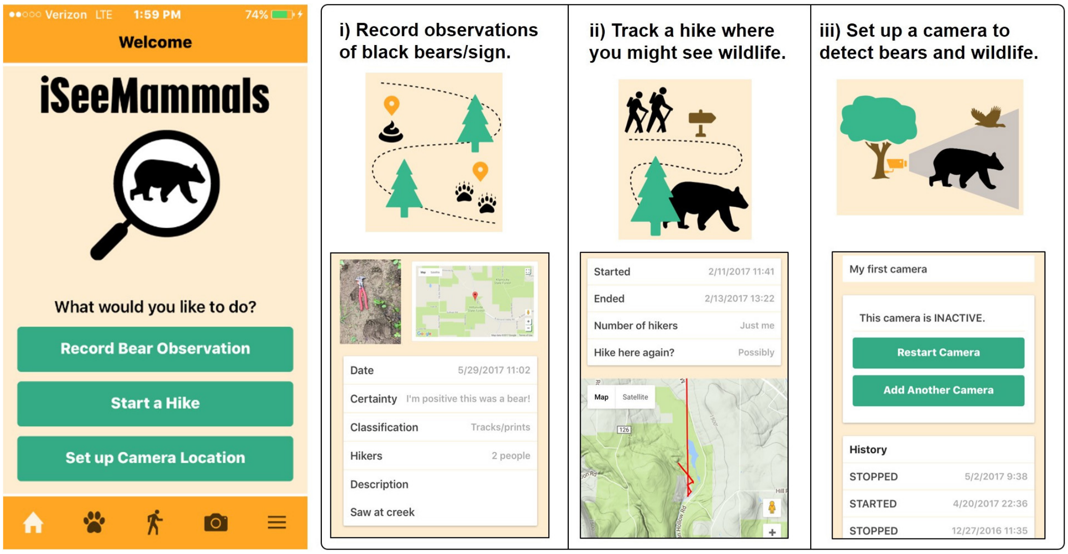

FIGURE 1 | Home screen of iSeeMammals smartphone app and the 3 ways to collect presence-only (PO) and presence-absence (PA) data on black bears in New York with observations, hikes, and camera traps. Users provide details, including time, location, and descriptions which can be viewed on the website and app. Some features can only be accessed with the app, including creation and tracking of a hike and recording the location of a camera trap. Other features can only be accessed with the website (not shown), including submission of camera trap photos.

user could attach observations based on submitted observations or photographs taken with the app during the hike. Hikes thus provided PA data, with absence information from the hike GPS coordinates and presence data from any associated observations.

Camera trap data consisted of the GPS coordinates of the camera, periods of operation, and any motion-triggered photographs of bears that were taken. Both the website and app were required to enter camera trap data; the app was necessary to automatically obtain GPS coordinates, while the website was necessary to upload photographs. Both the website and app could be used to provide records of each time the camera started and stopped and times of day the camera was scheduled to take pictures when triggered by motion. Users were required to explicitly report periods of operation rather than submit all camera trap photographs because a lack of motion-triggered photographs could be due to lack of wildlife rather than low sampling effort. When users checked on the camera trap to retrieve photographs, the app confirmed required information about camera trap location and setup, asked about periods of camera malfunction, and rhetorically asked whether or not bears were detected on the camera as a reminder to use the website for submitting photographs that contained bears. Users could also provide information about camera trap make and model. Camera traps thus provided PA data, with submitted photographs providing presence data and periods of camera operation providing absence information.

Users could delay submission by answering all questions to reach the submission page but then choose to save instead of submit. This enabled data collection on the app even when internet access or cell service were not immediately available, such as in rural or remote areas. Saved but un-submitted entries appeared with a red flag on the app and website to indicate that outstanding action remained for submission. Users were required to confirm or change their saved responses before final submission. On the website, a single page displayed all questions for each type of data and missing responses would trigger an error message; in the app, an arrow to proceed to the next question appeared when the question on the screen was answered.

We summarized the iSeeMammals data collected in its first year, between 1 January 2017 and 31 October 2017, reporting summary statistics and describing data filtering, data quality, and spatial patterns. We filtered out one-off observations that lacked spatial data or incorrect species identification based on the provided photograph, and duplicates based on photographs and descriptions. For hikes, we filtered out duplicates, hikes that were described as inaccurate by the user, and hikes that lasted <1 min or contained <2 sets of GPS coordinates. We filtered out camera traps that were only partially set up, lacked GPS coordinates, or had periods that monitored a location <1 day. If camera traps were still operating on 31 October 2017, we right-censored the period and assumed no malfunctions and no photographs/detections of bears.

RESULTS

The inaugural year of iSeeMammals was the first coordinated collection of opportunistic PA data on black bears in New York. iSeeMammals cost $32,000 USD to develop in the previous year (2016), which involved a local web and app development company that we hired on a pay-per services basis to develop and host the technology, and a team of 4 short-term high school and undergraduate research assistants compensated through university research and course credits. A total of 712 participants registered within the first 10 months, and 624 (88%) subsequently activated their accounts, which involved clicking on an email link sent after registration. iSeeMammals received a total of 629 one-off observations, hikes, and trail camera periods over a spatial extent of 113,392 km^2 (95% minimum convex polygon, MCP), from 126 users. The majority of submissions were one-off observations (79%). Most users (n = 118, 94%), submitted one-off observations, while 9 users submitted multiple types of data; 7 of 13 users who submitted trail camera data also submitted one-off observations; 1 of 3 users who submitted hike data also submitted one-off observations; one user submitted all three types of data.

iSeeMammals received 373 one-off observations that included all five types of bear sign (bear, scat, tracks, hair, markings; **Table 1**). We accepted 339 (91%) observations, having filtered out 14 misidentifications based on photographs, 8 duplicates, 10 with no spatial information, and 2 that users rescinded due to incorrect information. We further removed 49 observations (14%) from Pennsylvania, resulting in 290 accepted observations (86%) in New York (**Figure 2**), across 113,392 km^2 in 38 counties (95% MCP). A greater proportion of accepted observations reported confident identification compared to rejected observations (1.0 vs. 0.72, exact test 2-tailed $p < 0.001$). Photographs were included in 222 one-off observations (77%), although 25 were from camera traps of unregistered users. A greater proportion of observations with photographs reported bear signs rather than bears compared to observations without photographs (0.41 vs. 0.06, exact test 2-tailed $p < 0.001$). The average party size was 1.6 people; most observations (88%) were submitted by parties of 1 or 2 people (n = 150 and n = 105 observations, respectively), with 10 observations (3.4%) submitted by parties of ≥5 people.

iSeeMammals received 103 hikes (**Table 1**). We accepted 46 hikes (45%), after filtering out 49 hikes due to user-identified GPS inaccuracy, 5 duplicate hike entries, and 3 hikes with <2 pairs of GPS coordinates. We further filtered out 2 hikes in Pennsylvania, resulting in 44 accepted hikes (43%) in New York across 25,400 km^2 (95% MCP) in 8 counties (**Figure 2**). Of the accepted hikes in New York, 18 (41%) attached observations, with an average of 0.67 observations per hike. All hike observations were submitted with confidence. Most hikes (n = 37, 84%) had only 1 person, and most users indicated they would likely return to hike again in 3 months (n = 38, 86%). Average hike duration was 1.9 h (maximum of 4.7 h), totaling 82.3 h of effort. Hikes collected an average 24 GPS locations (range: 3–138) (**Figure 2**), resulting in a total of 1,264 correlated spatial PA data points in 44 sets.

iSeeMammals received data from 73 camera traps deployed at a total of 78 different locations (**Table 1**). We filtered out 16 trail cameras in Massachusetts and 4 periods of camera operation in New York that were less than 1 day. This resulted in 57 trail cameras in New York that operated continuously during 120 periods at 60 locations across 86,372 km^2 (95% MCP) in 12 counties (**Figure 2**). Periods of camera operation were an average 57 days per location (range: 8–153 days). However, two cameras malfunctioned a total of 14 days, resulting in 3,604 camera-days of sampling effort. iSeeMammals received 835 images of bears from 32 camera locations in New York, with an average of 25 photographs per location (range: 1–134 photographs). Eighteen cameras were still operating on October 31, 2017.

TABLE 1 | Between 1 January 2017 and 31 October 2017, iSeeMammals collected black bear data from one-off observations, hikes, and trail cameras in New York state.

Data type (# users)	Data type	Total submissions (% removed)	Accepted submissions in NY (% with pictures)
One-off observation (118)	**Presence-only**	**373 (9%)**	**290 (77%)**
Bear		221	194 (67%)
Scat		108	63 (94%)
Track		16	8 (100%)
Hair		5	4 (100%)
Markings		23	21 (100%)
Hike (4)	**Presence-absence**	**103 (56%)**	**44 (100%)**
Bear		17	17
Scat		12	11
Track		0	0
Hair		0	0
Markings		3	3
Camera traps (14)	**Presence-absence**	**78**	**60 (53%)**
Periods		153 (2%)	120 (67%)
Total (126)		629 (15%)	394

DISCUSSION

iSeeMammals collected spatiotemporally extensive PO and PA data that cost-effectively augmented the limited systematic PA dataset on black bears in New York state. Specifically, iSeeMammals collected data at 394 new locations in 38 counties over 7 additional months compared to the systematic SCR data that was collected at 241 locations in 17 counties in 3 months. Citizen science therefore increased the spatial extent of total research data on black bears in 2017 by 2.8-fold, the number of locations by 1.6-fold, and the temporal extent by 2.3-fold, while costing 83% less than annual SCR sampling. Data from neighboring states (i.e., Pennsylvania and Massachusetts) further highlighted the spatial extensiveness that is possible with a network of citizen science participants. Hikes and trail cameras covered one additional county in New York compared to the more numerous one-off observations, and importantly, seven counties not represented in the systematic sampling. iSeeMammals was not developed to replace the systematic collection of SCR data given the former's lack of individual-level information valuable for abundance estimation, but it successfully collected new and cheaper information to supplement SCR data and thereby potentially improve population estimation and ecological inference.

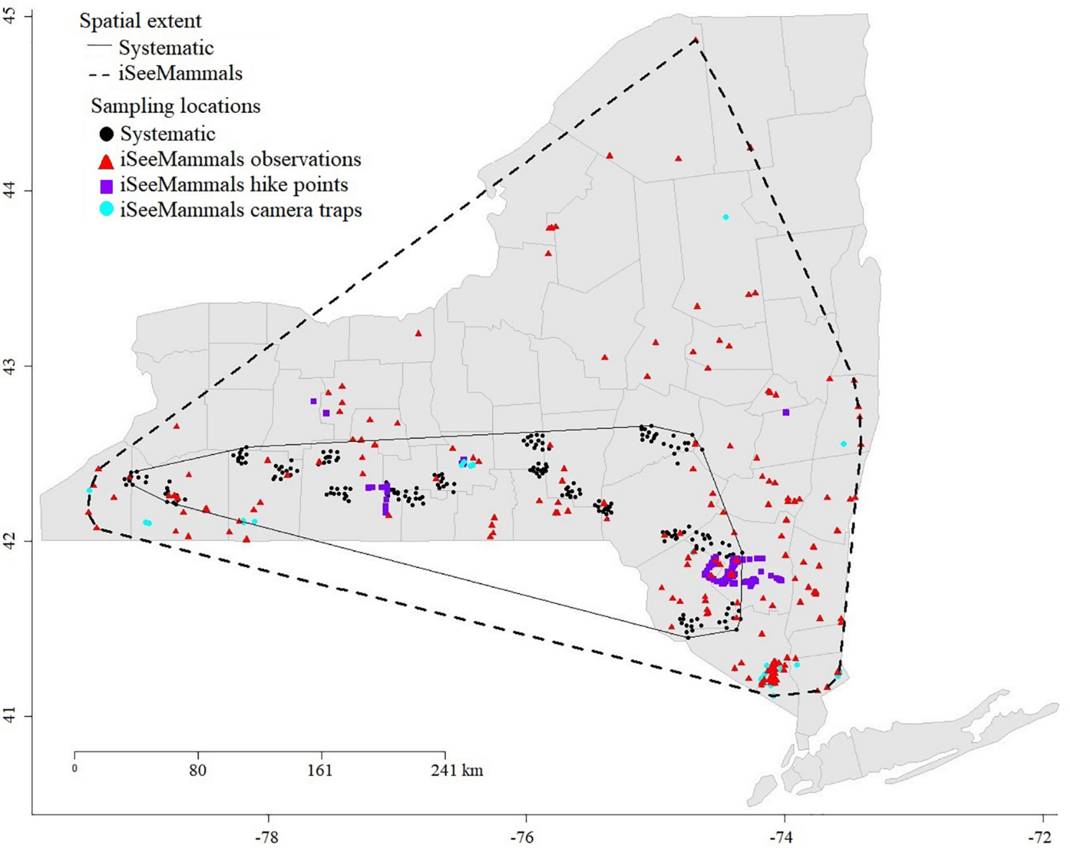

FIGURE 2 | Location of iSeeMammals one-off observations, hikes, and camera traps collected between 1 January 2017 and 31 October 2017 across New York state. Also shown, in black dots, are the location of 241 systematic SCR sites deployed from June to August, 2017. Light gray lines indicate county borders. The minimum convex polygons for the systematic (40,079 km^2) and iSeeMammals (113,392 km^2) sampling highlight the value of citizen science data for increasing spatial extent and quantity of data that can be collected. Coordinates shown in latitude and longitude.

Camera trapping is a common method for citizen science programs to monitor wildlife patterns (McShea et al., 2015; Willi et al., 2019). Integrated analyses offer an opportunity to extract even more value from these programs and data sets. To explore this potential with iSeeMammals, Sun et al. (2019) developed an integrated model to unite citizen science camera trap data with the systematic SCR data. They applied the model to estimate bear abundance in southeastern New York where the increasing bear population and frequency of human-bear interactions are of management concern (New York State Department of Environmental Conservation (NYSDEC), 2003). iSeeMammals contributed bear detections at 19 of 26 camera trap locations, adding to the 114 individual bears detected at 37 of 47 different SCR sites. iSeeMammals and SCR data were subset to the same time period (June–August 2017) and region (southeast New York) to ensure that datasets provided inference on the same population (Tenan et al., 2017). Compared to using only the SCR data, integrating iSeeMammals data increased precision of the abundance, estimate, by narrowing the 95% confidence intervals around the mean estimate by 206 individuals. The point estimate increased slightly from 3,663 to 3,702. The opportunistic iSeeMammals camera trap data thus contained sufficient information about population structure to improve abundance estimates, despite lacking individual level data and being relatively small due to the infancy of the program. With continued program maintenance, data collection, and the addition of a dedicated outreach specialist, which would in total not likely cost as much as annual SCR sampling, iSeeMammals may also be informative about population trends and improve estimates of demographic rates such as survival and recruitment (Sun et al., 2019). To identify optimal combinations of citizen science and systematic sampling, simulations of data collection and population analysis paired with cost comparisons would be required.

Other recently developed integrated models incorporate opportunistic PO data, presenting additional opportunities, risks, and challenges. Advances in modeling PO data as a thinned point process have made it possible to integrate PO data with systematic data based on an underlying spatial point process (Dorazio, 2014; Renner et al., 2015; Miller et al., 2019). This offers PO data additional robust modeling approaches. For PO data in the iSeeMammals program, the location of one-off observations could help identify and specify sources of spatial bias, such as proximity to human development, while party size could be used to account for variation in imperfect detection, such as increased collective effort or reduced effort due to social distraction. However, we caution that while statistical techniques can compensate for low quality data or account for variation and biases common in and across citizen science datasets (Kelling et al., 2015; Johnston et al., 2018)—PO or otherwise—analytical fixes are not a substitute for carefully designed data collection and submission protocols. We therefore highlight the importance of developing and adopting data and metadata standards and minimum requirements (Storksdieck et al., 2016; Bowser et al., 2020), similar to efforts by global networks for camera trap data to facilitate collaboration across programs (Forrester et al., 2016; Steenweg et al., 2017). In this way, citizen science datasets can be used repeatedly to synthesize knowledge across scales, guide conservation strategies, and shape policy (Newman et al., 2011; Burgess et al., 2017; Curty et al., 2017; Fritz et al., 2019).

Patterns of iSeeMammals data filtering suggested that not all forms of PO data may be equally amenable to citizen science data collection or useful for ecological inference and integrated analyses. Hikes may not be an efficient source of opportunistic PA data, given that they were the least submitted and most filtered data type. Citizen science participants may not be willing to modify their hiking patterns while recreating in order to adhere to detection protocols such as minimum durations or distances. Furthermore, while hikes could be considered transect data for distance sampling (Buckland et al., 2012; Kumar et al., 2017), detection probability likely decreases sharply with distance from the trail path, and so hikes may provide limited spatial inference. Human activity in general may also hinder detection and bias sampling with opportunistic approaches, by displacing wildlife and altering their fine-scale spatial patterns of habitat use or temporal activity patterns to locations where and times when humans are not present (Larson et al., 2019; Zeller et al., 2019; Naidoo and Burton, 2020). Sensitivity analyses would be needed to explore the value of hike data in integrated models. Instead, citizen science participants may be more willing to follow guidelines for camera trap data, which have already proven useful in integrated analyses. Standards or minimum metadata requirements such as camera model and placement (e.g., height off ground and camera angle; Burton et al., 2015), would be helpful in accounting for detection probability, especially when focal species for monitoring are smaller-bodied. The marginal benefit of citizen science data for statistical analyses therefore depends on the information content about ecological patterns (Callaghan et al., 2019) as well as the relative ease of collection while maintaining data quality.

Indeed, citizen science data of sufficient quality and quantity rely on user-facing protocols that successfully engage with the target participant demographics. To develop a viable platform that balanced data needs with accessibility and usability, we conducted several rounds of beta-testing and expected results from the first year to provide feedback for improvement (i.e., lean product development, Poppendieck and Poppendieck, 2003). We targeted outreach to adults who were likely already familiar with or interested in wildlife, but the low participation rate (18%) suggests that protocols could have better matched participant motivations (Rotman et al., 2012; Beirne and Lambin, 2013; Eveleigh et al., 2014; Nov et al., 2014). Future iterations of the platform would benefit from tracking patterns of online versus smartphone app submission and demographics of the actual users such as gender, age, access to the outdoors, and familiarity with wildlife, in order to help develop strategies for engagement and retention. Importantly, a focus more on Generation Y and Generation Z participants (i.e., born since the 1980s), and even younger, could markedly increase participation and data quantity, given the ease of data collection with smartphones and the large amount of time that these age groups spend with developing technologies (Mutchler et al., 2011)—often to the point of technology mediating their recreation and time spent in nature (Barton, 2012; Wang et al., 2012). For example, social media posts of images and videos with date and timestamps can contain valuable ecological information (Dylewski et al., 2017; Toivonen et al., 2019) that could be collected in a formal citizen science framework. Gamification of data collection tasks have also been found to be effective at engaging younger demographics, who are already familiar with apps and features such as augmented reality (Bowser et al., 2013; Iacovides et al., 2013; Malik et al., 2020). Incidentally, gamification could also guide sampling to particular time periods or regions with data gaps in citizen science or systematic data (Xue et al., 2016; Callaghan et al., 2019). Additional participant-oriented objectives, such as science education and addressing the nature-deficit disorder, could both sustain participation in younger generations (Barton, 2012) and encourage collection of the more complex and robust PA data (Chase and Levine, 2016). Improving citizen science data quality and quantity will therefore benefit from improving engagement, accessibility, and usability, especially for younger demographics.

Citizen science is increasingly acknowledged for its ability to contribute to wildlife monitoring and management (McKinley et al., 2017). Cost efficiencies suggest that citizen science approaches can become an integral component of long term monitoring and supplement more costly systematic sampling (De Barba et al., 2010). iSeeMammals in its first year illustrated how citizen science programs can collect data for integrated analyses to support and improve population estimation. We reiterate calls to prioritize protocols that collect PA data, for their relative robustness in comparison to PO data for standalone and integrated analyses. Also critical are approaches to data collection that reserve the capacity for a range of currently available and future analyses, and therefore also times that datasets can be used to answer different questions (Curty et al., 2017) as statistical developments expand the toolbox and take advantage of different types of data (Miller et al., 2019). To further facilitate collaborations and ask new questions with integrated models, we also recommend greater emphasis and uptake of data standards and minimum requirements to ensure data quality across citizen science programs, and that younger demographics be explicitly considered when developing strategies for engagement. In this way, citizen science can continue to meet the increasing need for ecological knowledge at scales and extents larger than individual datasets (Silvertown, 2009; Theobald et al., 2015).

DATA AVAILABILITY STATEMENT

Requests to access the datasets should be directed to the corresponding author CS, Catherine.c.sun@gmail.com.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because while the research pertains to vertebrate wildlife, data were collected only with non-invasive observations without any direct interactions with animals.

AUTHOR CONTRIBUTIONS

CS, JH, and AF contributed to conception and design of the study. CS conducted the research and analyses and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Reliability of Data Collected by Volunteers: A Nine-Year Citizen Science Study in the Red Sea

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The quality of data collected by non-professional volunteers in citizen science programs is crucial to render them valid for implementing environmental resources management and protection plans. This study assessed the reliability of data collected by non-professional volunteers during the citizen science project Scuba Tourism for the Environment (STE), carried out in mass tourism facilities of the Red Sea between 2007 and 2015. STE involved 16,164 volunteer recreational divers in data collection on marine biodiversity using a recreational citizen science approach. Through a specifically designed questionnaire, volunteers indicated which of the seventy-two marine taxa surveyed were observed during their recreational dive, giving an estimate of their abundance. To evaluate the validity of the collected data, a reference researcher randomly dived with the volunteers and filled in the project questionnaire separately. Correlation analyses between the records collected by the reference researcher and those collected by volunteers were performed based on 513 validation trials, testing 3,138 volunteers. Data reliability was analyzed through 7 parameters. Consistency showed the lowest mean score (51.6%, 95% Confidence Interval CI 44.1–59.2%), indicating that volunteers could direct their attention to different taxa depending on personal interests; Percent Identified showed the highest mean score (66.7%, 95% CI 55.5–78.0), indicating that volunteers can correctly identify most surveyed taxa. Overall, results confirmed that the recreational citizen science approach can effectively support reliable data for biodiversity monitoring, when carefully tailored for the volunteer skills required by the specific project. The use of a recreational approach enhances massive volunteer participation in citizen science projects, thus increasing the amount of sufficiently reliable data collected in a reduced time.

Keywords: citizen science, reliability, data quality, volunteers, biodiversity monitoring

INTRODUCTION

Institutions and natural resource managers are often under fund restrictions, which odds with the need to collect fundamental data to implement conservation strategies (Lewis, 1999; Foster-Smith and Evans, 2003; Jetz et al., 2012; Forrester et al., 2015; McKinley et al., 2017). Effective conservation strategies must also integrate public input and engagement in designing solutions (McKinley et al., 2017). Involving volunteers in data collection for monitoring activities can be a cost-effective strategy to complement or replace the information collected by professionals (Starr et al., 2014). Citizen science projects can improve environmental education of volunteers, increase scientific knowledge and allow the collection of large datasets (Foster-Smith and Evans, 2003; Bonney et al., 2009; Sullivan et al., 2009; Jordan et al., 2011; Branchini et al., 2015b; Callaghan et al., 2019). Participating in a citizen science project can have an educational role both in the short and long term, with the retention of acquired environmental awareness after years (Branchini et al., 2015a; Meschini et al., 2021).

Observations of the natural world, including weather information, plants and animals distribution, astronomical phenomena and many other data have been recorded for decades by citizens (Miller-Rushing et al., 2012; Bonney et al., 2014). One emblematic example come from ornithology, with the Audubon Society's annual Christmas bird counts, started in 1900 and it still engaging 60–80,000 volunteers annually (Forrester et al., 2015). Nowadays millions of volunteers are participating in many scientific research projects by collecting, categorizing, transcribing and analyzing data (Dickinson et al., 2012; Callaghan et al., 2019). Ultimately, citizen science presents an enormous potential to influence policy and guide resource management by producing datasets that would be otherwise unobtainable (Kosmala et al., 2016).

Citizen science is blooming across a range of disciplines in natural and social sciences, as well as humanities (Lukyanenko et al., 2019). A large body of environmental research is based on citizen science (e.g., biology, conservation and ecology); anyway, the development of information and communication technologies (ICT) have expanded the scale and scope of data collection from geographic information research (e.g., projects for geographic data collection) to social sciences and epidemiology studies (e.g., projects that study the relationship between environmental issues and human health) (Kullenberg and Kasperowski, 2016; Hecker et al., 2018). Citizen science is becoming of central importance to reinforce literacy and societal trust in science and foster participatory and transparent decision-making[1]. It is also gaining an increasing interest for policy makers, government officials and non-governmental organizations (Turbé et al., 2019). Data collected through citizen science are a non-traditional data source that is giving a contribution to measure the United Nations (UN) Sustainable Development Goals (Fritz et al., 2019). The role of citizens is becoming central also in European Union (EU) policies, such as the Horizon 2020 funding program[2]. The next European Research and Innovation Program Horizon Europe includes a specific mission supporting this process by connecting citizens with science and public policy[3]. In the Mission Starfish 2030 program, citizens are protagonists of one of the five overarching objectives for 2030 and one goal of this program for the 2025 checkpoint, is that 20% of data collection comes from citizen science initiatives[4]. Those are some examples of the increasing importance that citizen science is gaining in European funding programs, where citizen science will be a transversal topic to all missions.

Citizen science projects vary extensively in subject matter, objectives, activities, and scale, but the common goal is collecting reliable data to be used for scientific and policy making purposes for implementing environmental management and protection plans (Forrester et al., 2015; Van der Velde et al., 2017). Volunteers involved in citizen science projects can produce data with sufficient to high accuracy (Foster-Smith and Evans, 2003; Goffredo et al., 2010; Kosmala et al., 2016), although some cases of insufficient volunteer data quality have been reported (Foster-Smith and Evans, 2003; Galloway et al., 2006; Delaney et al., 2008; Silvertown, 2009; Hunter et al., 2013).

Data collection in citizen science projects usually addresses easy-to-recognize organisms, with interest on qualitative and semi-quantitative data that can be useful for management plans (Bramanti et al., 2011). The marine environment data collection is particularly challenging because it requires swimming or scuba diving skills in addition to the usual sampling difficulties (Goffredo et al., 2004, 2010; Gillett et al., 2012; Forrester et al., 2015). Citizen science in the marine environment can be used to monitor shallow water organisms (up to 40 meters depth, the Professional Association of Diving Instructors (PADI) limit for recreational scuba skills) over a large geographical and temporal extension (Goffredo et al., 2010; Bramanti et al., 2011; Gommerman and Monroe, 2012). Several studies analyzed the correlation between data collected by professionals and volunteers on a single taxonomic group, such as fishes (Darwall and Dulvy, 1996; Holt et al., 2013), e.g., sharks (Ward-Paige and Lotze, 2011) or corals (Bramanti et al., 2011; Marshall et al., 2012; Forrester et al., 2015) showing that volunteers were able to collect good quality data that could be used to complement professional data and describe population trends in spatial and temporal scales.

The aim of this study was to replicate the standardized methodology used in Goffredo et al. (2010) and Branchini et al. (2015b) to assess the quality of data collected by non-specialist volunteers on seventy-two Red Sea taxa during the recreational citizen science project Scuba Tourism for the Environment (STE). Previous reported studies were, respectively, based on 38 and 61 validation trials, in this study we analyzed 513

[1]https://cordis.europa.eu/programme/id/H2020_IBA-SWAFS-Citizen-2019

[2]https://ec.europa.eu/programmes/horizon2020/en/h2020-section/science-and-society

[3]https://ec.europa.eu/info/horizon-europe_en

[4]https://ec.europa.eu/info/publications/mission-starfish-2030-restore-our-ocean-and-waters_en

validation trials mainly performed in Egypt between 2007 and 2015. Our study used a recreational survey protocol based on casual diver observations. This protocol allowed divers to carry out their normal recreational activities and ensured the reliability of collected data through standardized data collection (Branchini et al., 2015b). To evaluate the possible influence of independent variables (date, team size, diving certification level, depth and dive time on volunteers data quality, we used correlation analyses using Spearman rank correlation and distance-based redundancy linear modeling (DISTLM) to test the contributions of independent variables to data variability.

MATERIALS AND METHODS

From 2007 to 2015 16,164 recreational scuba divers in mass tourism facilities and diving centers in the Red Sea were involved in the citizen science project Scuba Tourism for the Environment (STE). Project goal was to monitor coral reef biodiversity in the Red Sea, using specifically developed illustrated questionnaires. A first section of the questionnaire was dedicated to volunteer environmental education to limit human impact on the reef and increase volunteer awareness on the vulnerability of coral reefs (**Supplementary Figure 1**). The second section of the questionnaire consisted in seventy-two photographs of target taxa, chosen because they are: (i) representative of the main ecosystem trophic levels, (ii) expected to be common and abundant in the Red Sea, and (iii) easily recognizable by non-specialist volunteers (**Supplementary Figure 2**). These characteristics were selected to increase the accuracy of data collected by volunteers (Goffredo et al., 2004, 2010). The third section of the questionnaire was dedicated to the collection of personal information (i.e., name, address, email, level of diving

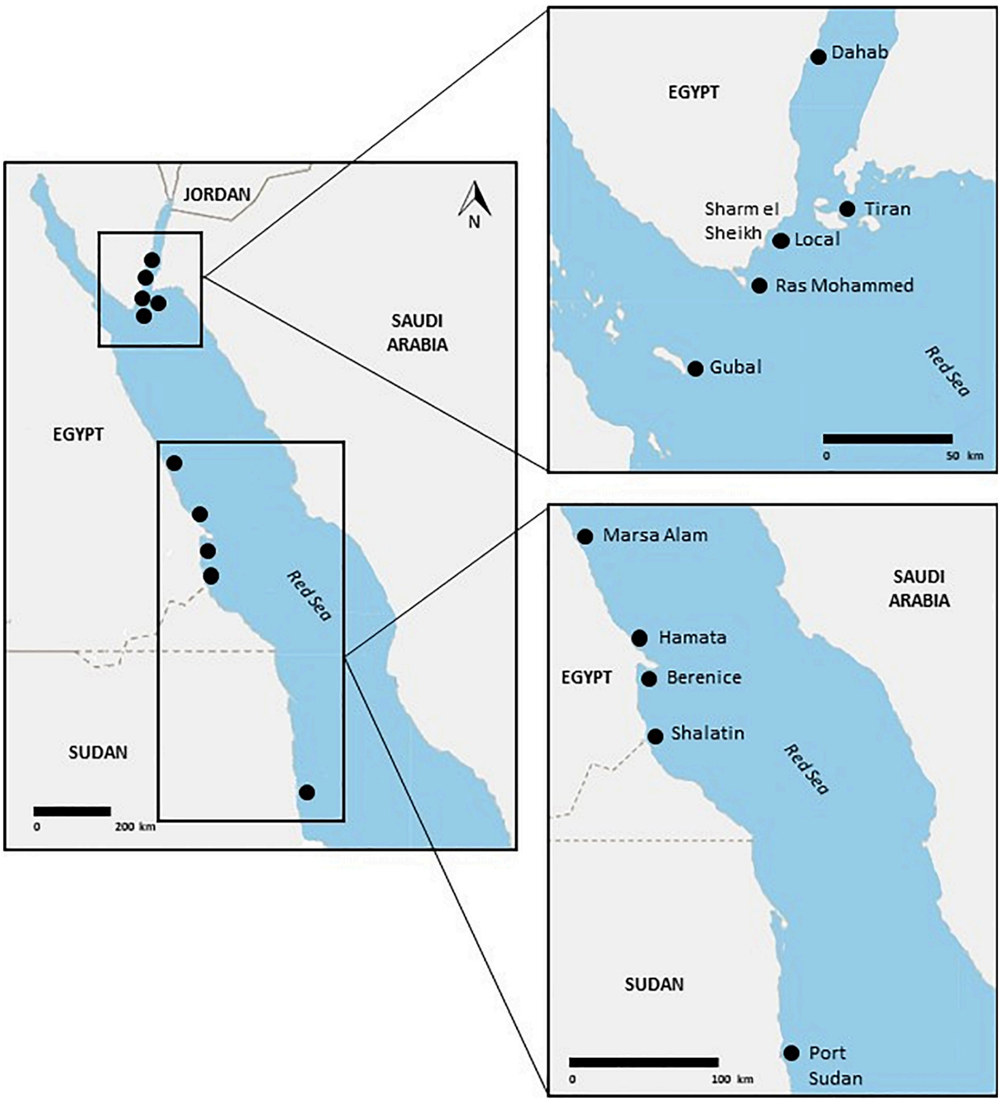

FIGURE 1 | Red Sea map with black dots indicating sites in which data for the reliability analysis were collected.

certification and diving agency), technical information about the dive (i.e., place, date, depth, dive time, duration of the dive), type of habitat explored (i.e., rocky bottom, sandy bottom or other habitat) and the data collection table about sighted taxa with an estimation of their abundance (**Supplementary Figure 3**). The abundance estimation of each taxon was based on literature (Wielgus et al., 2004) and databases[5], and expressed in the three categories "rare," "frequent" or "abundant." Completing questionnaires shortly after the dive facilitated the quality control of collected data. The STE project used a recreational citizen science approach (Goffredo et al., 2004, 2010; Branchini et al., 2015b) in which normal recreational diving features and volunteer behavior are not modified by project participation. Researchers of the STE project performed an annual training session for scuba instructors of the diving centers involved in the project, based on the methodology used for the study and obtained results. This allowed scuba instructors to directly involve their clients in data collection. The STE project received the approval of the Bioethics Committee of the University of Bologna (prot. 2.6). Data were treated confidentially, exclusively for institutional purposes (art. 4 of Italian legislation D.R. 271/2009 – single text on privacy and the use of IT systems). Data treatment and reporting took place in aggregate form.

Data Validity Assessment

To assess the validity of data collected by volunteers, records of 3,138 volunteer were compared with those collected by a marine biologist of the Marine Science Group of the University of Bologna ("control diver") during 513 validation trials mainly performed in Egypt (**Figure 1**). The characteristics of the validation trials were: (1) the control diver dived with at least three volunteers; (2) the validation trial did not affect the diving center normal choice of dive site; (3) the dive was conducted between 9.00 am and 4.00 pm; (4) after the dive, the control diver filled in the questionnaire apart from volunteers, as to avoid interference with volunteers data recording (Goffredo et al., 2010). For each trial, the inventory of each taxa (with abundance ratings) sighted by the control diver was correlated with that collected by each volunteer to verify their similarity (Darwall and Dulvy, 1996; Foster-Smith and Evans, 2003; Aceves-Bueno et al., 2017). To measure the quality of volunteer data, 7 reliability parameters were used: Accuracy, Consistency, Percent Identified, Correct Identification, Correctness of Abundance Ratings, Similarity, Reliability (**Table 1**). Non-parametric statistical tests were used for the analysis: (1) Spearman rank correlation coefficient, to evaluate the accuracy of data collected by volunteers in comparison to those obtained by the control diver; (2) Cronbach's alpha (α) correlation, to evaluate the reliability of collected data between each volunteer and the control diver; and (3) Czekanowski proportional similarity index (SI) to obtain a measure of similarity between each volunteer and the control diver ratings (Goffredo et al., 2010). Tests results were reported as mean with 95% Confidence Interval (CI) (Sale and Douglas, 1981; Darwall and Dulvy, 1996). For the Similarity and Reliability parameters the lower bound (calculated from 95% Confidence Interval (CI) of the mean values) was used (Goffredo et al., 2010). We also examined the effect of date, team size (the number of participants present in each validation trial), diving certification level of each participant, depth and dive time on volunteer accuracy using the Spearman's rank correlation coefficient. All these statistical analyses were computed using the SPSS 22.0 statistical software. Using PRIMER v6, distance-based redundancy linear modeling (DISTLM) with a test of marginality was also performed, based on Euclidean distance, to test the contributions of variables to data variability.

RESULTS

The mean accuracy of each validation trial ranged from 38.2 to 81.5%, with 94.2% of trials with mean accuracy between 40 and 70% (**Supplementary Table 1**; **Figure 2**). Accuracy

[5]http://www.gbif.org; http://www.marinespecies.org

TABLE 1 | Reliability parameters used to analyze data collected by volunteers (modified from Goffredo et al., 2010).

Parameter	Definition and derivation of parameter
Accuracy	Similarity of volunteer-generated data to reference values from a control diver measured as Spearman rank correlation coefficient (rho) and expressed as a percentage in the text. This measure of accuracy is assumed to encompass all component sources of error.
Consistency	Similarity of data collected by separate volunteers during the same dive. This was measured as rank correlation coefficient and expressed as percentage in the text. This measure of consistency is assumed to encompass all component source of error.
Percent identified	The percentage of the total number of taxa present that were recorded by the volunteer diver. The total number of taxa present was derived from the control diver data (i.e., we assumed the taxa recorded by the control diver to be all the taxa present).
Correct identification	The percentage of volunteers that correctly identified individual taxa when the taxon was present.
Correctness of abundance ratings (CAR)	This analysis quantified the correctness in abundance ratings made by the volunteer. It has been expressed as the percentage of the 72 surveyed taxa whose abundance has been correctly rated by the volunteer (i.e., the value of the rating indicated by the volunteer was equal to the reference value recorded by the control diver).
Similarity index	Measure of similarity between each volunteer and the control diver ratings, using Czekanowski proportional similarity index.
Reliability	Measure of reliability between each volunteer and the control diver ratings, using Cronbach alpha (α) correlation.

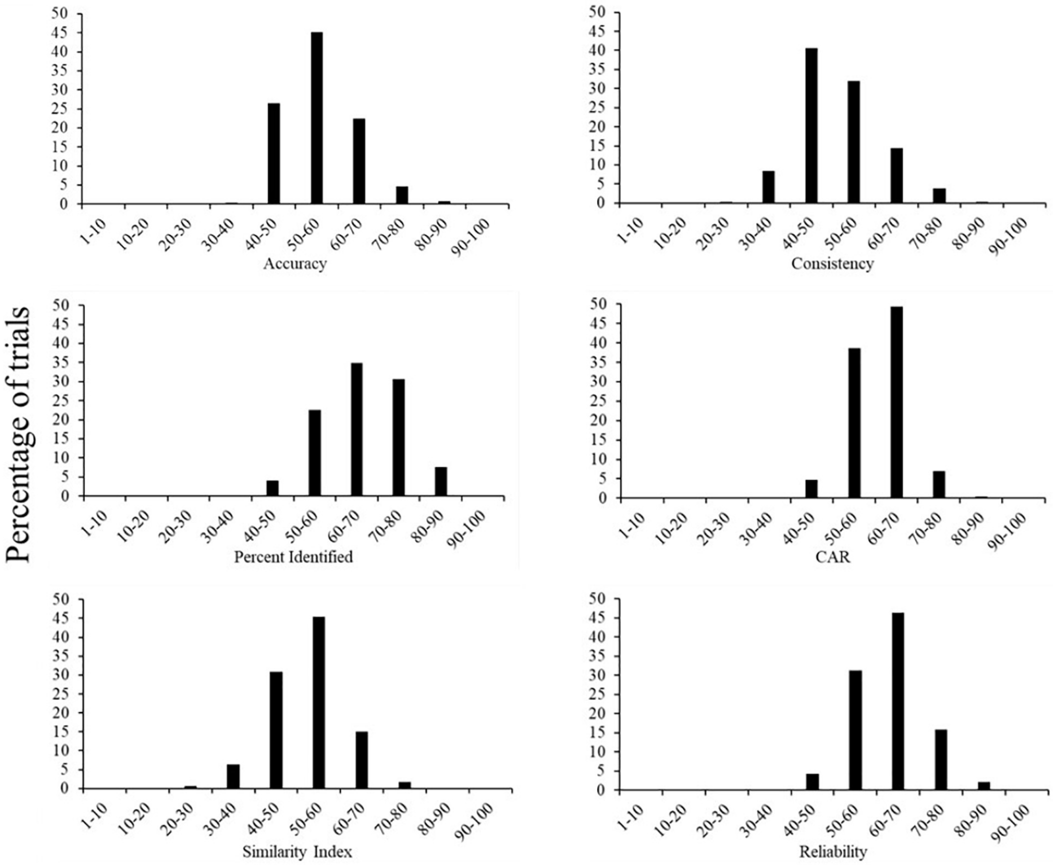

FIGURE 2 | Quality of data collected by volunteers in the 513 validation trials performed during the 9-year research project STE (2007–2015). Distribution of data is divided in classes depending on the mean score percentage that each validation trial achieved for the studied parameters. For the parameters Similarity Index and Reliability the reference score is the lower bound calculated from 95% CI of the mean values.

TABLE 2 | Correlations between reliability parameters and independent variables.

	Date	Team size	Diving certification level	Depth	Dive time
Accuracy	0.120**	0.063	0.242***	−0.022	0.122**
Consistency	−0.022	−0.077	0.165***	−0.049	0.117**
Percent identified	−0.005	−0.020	0.272***	0.009	0.164***
CAR	0.110*	0.135**	−0.020	−0.084	0.016
Similarity Index	0.032	0.107*	0.253***	−0.004	0.186***
Reliability	0.029	0.212***	0.200***	−0.024	0.145***

*Reported number are Spearman Rho (ρs) values, significance of correlation is indicated as *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$.*

was positively correlated with: date (ρs = 0.120, N = 513, $p < 0.01$, **Table 2**; **Figure 3**), volunteers scores increased with years, with a score increase of 2.8% between the start and the end of the project (**Table 3**); volunteer diving certification level (ρs = 0.242, N = 513, $p < 0.001$, **Table 2**; **Figure 4**), volunteers scores increased with higher divers certification level, with an increase of 17.3% between beginners and professional divers (**Table 3**); dive time (ρs = 0.122, N = 513, $p < 0.01$, **Table 2**; **Figure 4**), volunteers scores increased with time spent underwater, with an increase of 11.6% between short and long dives (**Table 3**). Accuracy was not correlated with team size (ρs = 0.063, N = 513, p = 0.151, **Table 2**) and depth (ρs = −0.022, N = 513, p = 0.620, **Table 2**).

The mean consistency of each validation trial ranged from 28.0 to 85.3%, with 86.9% of trials with mean consistency between 40 and 70% (**Supplementary Table 1**; **Figure 2**). Consistency was positively correlated with: volunteer diving certification level (ρs = 0.165, N = 513, $p < 0.001$, **Table 2**; **Figure 4**), volunteers scores increased with higher divers certification level, with a score increase of 13.6% between beginners and professional divers (**Table 3**); dive time (ρs = 0.117, N = 513, $p < 0.01$, **Table 2**; **Figure 4**), volunteers scores increased with time spent underwater, with an increase of 17.7% between short and long dives (**Table 3**). Consistency was not correlated with date (ρs = −0.022, N = 513, p = 0.615, **Table 2**), team size (ρs = −0.077, N = 513, p = 0.81, **Table 2**) and depth (ρs = −0.049, N = 513, p = 0.271, **Table 2**).

The mean percent identified of each validation trial ranged from 40.2 to 90.9%, with 88.1% of trials with mean percentage of identified between 50 and 80% (**Supplementary Table 1**;

Figure 2). Percent identified was positively correlated with: volunteer diving certification level (ρs = 0.272, $N = 513$, $p < 0.001$, **Table 2**; **Figure 4**), volunteers scores increased with higher divers certification level, with a score increase of 21.4% between beginners and professional divers (**Table 3**); dive time (ρs = 0.164, $N = 513$, $p < 0.001$, **Table 2**; **Figure 4**), volunteers scores increased with time spent underwater, with an increase of 17.1% between short and long dives (**Table 3**). Percent identified was not correlated with date (ρs = −0.005, $N = 513$, $p = 0.904$, **Table 2**), team size (ρs = −0.020, $N = 513$, $p = 0.656$, **Table 2**) and depth (ρs = 0.009, $N = 513$, $p = 0.831$, **Table 2**).

The mean correct identification of each taxon varied from 3.8 to 94.7%, with a positive correlation between the number of validation trials in which the taxon was present and the level of correct identification performed by volunteers (ρs = 0.610, $N = 77$, $p < 0.001$), with a score increase of 21.5% between less present and most present taxa (**Table 4**; **Figure 5**).

The mean correctness of abundance ratings (CAR) of each validation trial ranged from 41.1 to 82.3%, with 94.9% of trials with mean CAR between 50 and 80% (**Supplementary Table 1**; **Figure 2**). CAR was positively correlated with: date (ρs = 0.110, $N = 513$, $p < 0.05$, **Table 2**; **Figure 3**), volunteers scores increased with years, with a score increase of 7.8% between the start and the end of the project (**Table 3**) and team size (ρs = 0.135, $N = 513$, $p < 0.01$, **Table 2**; **Figure 3**), volunteers scores increased with number of present divers, with a score increase of 6.9% between small and big groups (**Table 3**). CAR was not correlated with volunteer diving certification level (ρs = −0.020, $N = 513$, $p = 0.657$, **Table 2**), depth (ρs = −0.084, $N = 513$, $p = 0.057$, **Table 2**) and dive time (ρs = 0.016, $N = 513$, $p = 0.721$, **Table 2**).

The mean lower bound of the Czekanowski proportional similarity index (SI) of each validation trial ranged from 27.3 to 78.8%, with 91.2% of trials with mean SI between

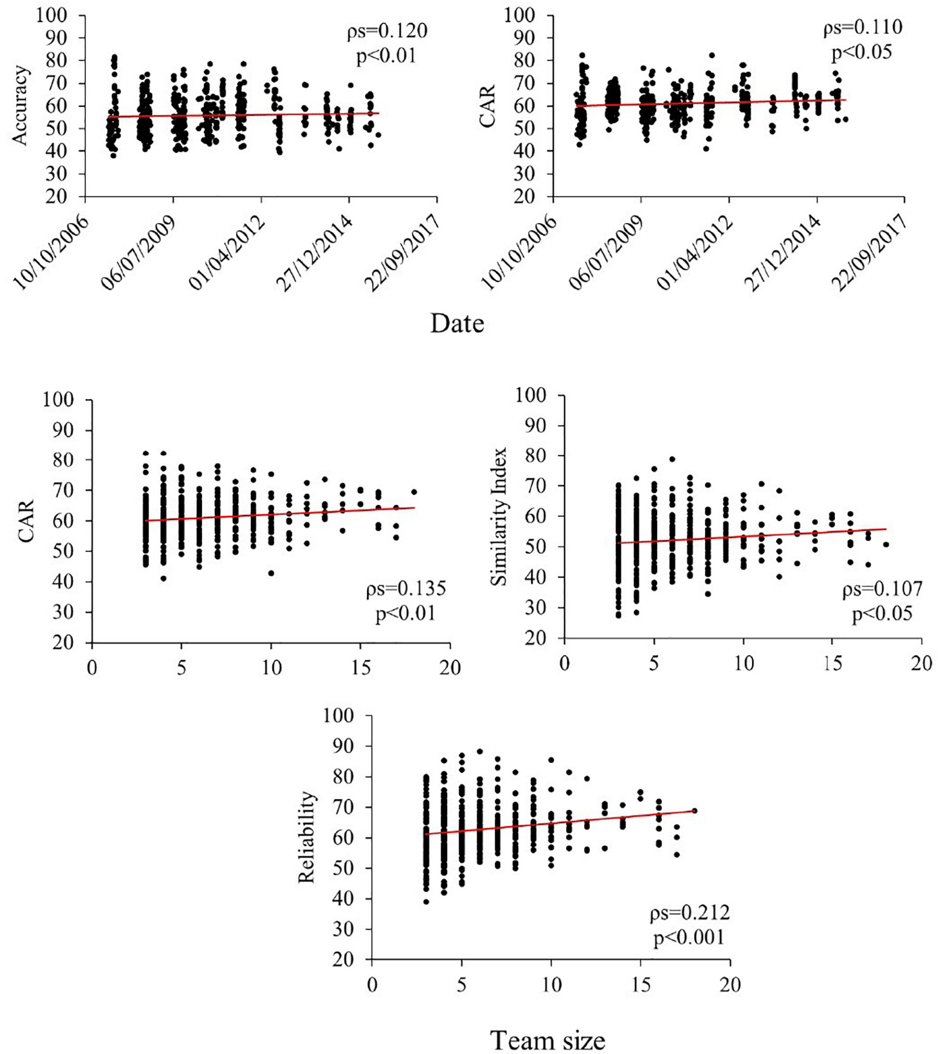

FIGURE 3 | Significant correlations between reliability parameters (Accuracy, CAR, Reliability, and Similarity Index) and independent variables (Date and Team Size). Results based on the 513 validation trials. Indicated in red the trendline of the correlations. ρs = Spearman correlation coefficient.

TABLE 3 | Percentage of increase of reliability parameters depending on independent variables.

	Date	Team size	Diving certification level	Depth	Dive time
Accuracy	2.837	–	17.349	–	11.586
Consistency	–	–	13.570	–	17.674
Percent identified	–	–	21.432	–	17.115
CAR	7.772	6.914	–	–	–
Similarity index	–	8.746	21.223	–	21.432
Reliability	–	12.430	11.138	–	11.046

This increase has been calculated from the trend line equation, using minimum and maximum value for each independent variable.

40 and 70% (**Supplementary Table 1**; **Figure 2**). A 194 trials (37.8%) performed with levels of precision below the sufficiency threshold (SI, 95% CI lower bound ≤ 50%); 317 trials (61.8%) scored a sufficient level of precision (SI, 95% CI lower bound > 50% ≤ 75%), and 2 trials (0.4%) scored high levels of precision (SI, 95% CI lower bound > 75% ≤ 100%). SI was positively correlated with: team size (ρs = 0.107, N = 513, p < 0.05, **Table 2**; **Figure 3**), volunteers scores increased with number of present divers, with a score increase of 8.7% between small and big groups (**Table 3**); volunteer diving certification level (ρs = 0.253, N = 513, p < 0.001, **Table 2**; **Figure 4**), volunteers scores increased with higher divers certification level, with a score increase of 21.2% between beginners and professional divers (**Table 3**); dive time (ρs = 0.186, N = 513, p < 0.001, **Table 2**; **Figure 4**), volunteers scores increased with time spent underwater, with an increase of 21.4% between short and long dives (**Table 3**). SI was not correlated with date (ρs = 0.032, N = 513, p = 0.465, **Table 2**) and depth (ρs = −0.004, N = 513, p = 0.924, **Table 2**).

The mean lower bound reliability (α) of each validation trial ranged from 38.9 to 88.4%, with 93.4% of trials with

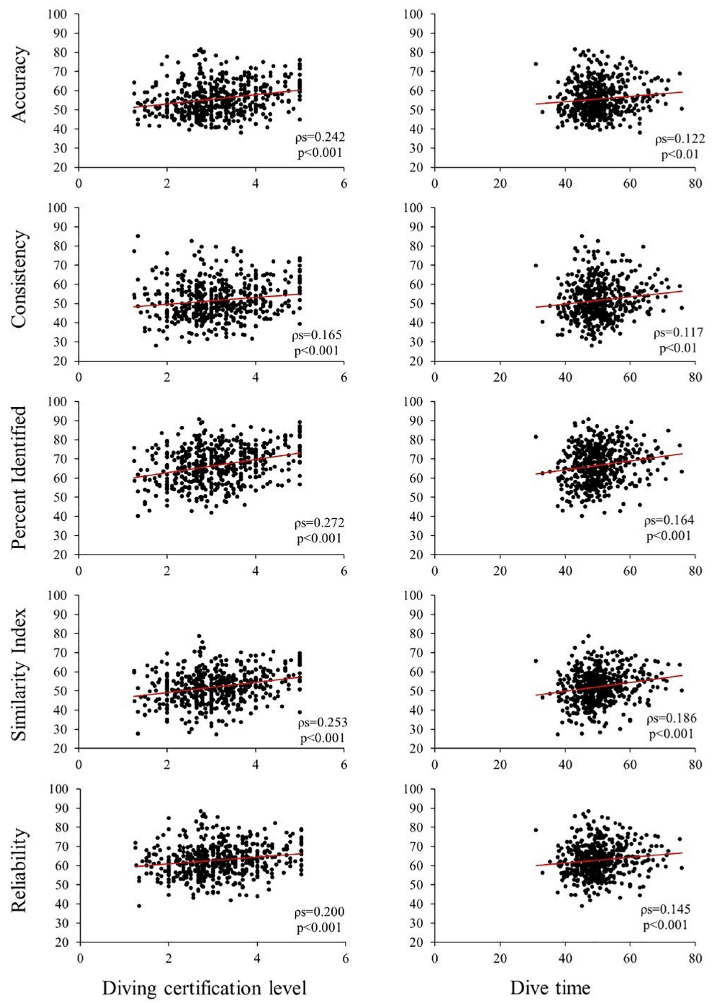

FIGURE 4 | Significant correlations between the studied reliability parameters (Accuracy, Consistency, Percent Identified, Similarity Index, and Reliability) and the independent variables Diving certification level and Dive time. Results based on the 513 validation trials. Indicated in red the trendline of the correlations. ρs = Spearman coefficient value.

TABLE 4 | Results of the correct identification analysis with mean score of correct identification performed by volunteers for each taxon.

Taxon		Correct identification			
Common name	**Scientific name**	**Mean**	**N**	**95% CI**	
2-fire coral	*Millepora sp.*	94.7	507	93.6	95.7
5-sea fan	*Subergorgia hicksoni*	91.8	415	90.2	93.4
4-soft tree coral	*Dendronephthya sp.*	91.1	494	89.7	92.4
23-tbigfin reef squid	*Sepioteuthis sp.*	90.0	1	–	–
46-parrotfishes	Scaridae	85.1	475	83.6	86.7
35-groupers	Epinephelinae	83.9	488	82.3	85.6
42-butterflyfishes	Chaetodontidae	83.9	488	82.3	85.5
22-squids	Seepidae	83.3	2	50.7	100
9-plating acropora	*Acropora sp.*	83.3	462	81.5	85.1
44-Red Sea clownfish	*Amphiprion bicinctus*	82.1	392	80.0	84.2
1-tube sponge	*Siphonochalina sp.*	82.1	418	80.2	84.0
3-leather coral	*Sarcophyton sp.*	80.7	497	78.7	82.6
56-sharks	Squaliformes	80.7	55	73.0	88.4
20-tridacnae	*Tridacna sp.*	79.4	456	77.5	81.3
18-spanish dancer	*Hexabranchus sanguineus*	77.0	7	57.5	96.5
– broken corals		76.9	459	74.9	79.0
62-partially or totally dead corals		76.7	440	74.5	78.9
12-mushroom corals	Fungiidae	76.0	466	74.0	77.9
49-caranxes	Carangidae	74.0	417	71.6	76.5
60-turtles	Cheloniidae	73.7	85	68.0	79.4
63-bleached corals		73.2	337	70.8	75.6
32-giant moray	*Gymnothorax javanicus*	72.5	204	68.4	76.6
7-sea whips	Ellisellidae	71.5	337	69.0	74.1
13-lettuce coral	*Turbinaria sp.*	70.9	284	67.8	74.0
47-barracuda	*Sphyraena sp.*	70.7	117	65.1	76.2
8-sea carpet host anemones	Stichodactylidae	69.8	412	67.4	72.2
37-humpback batfish	*Platax sp.*	68.5	147	63.8	73.1
10-porcupine coral	*Seriatopora hystrix*	68.4	372	65.9	70.9
45-humphead wrasse – Napoleon fish	*Cheilinus undulatus*	68.1	218	64.0	72.2
50-lionfish	*Pterois sp.*	65.8	304	62.8	68.8
41-map angel	*Pomacanthus maculosus*	65.4	257	62.4	68.4
Other sponges		65.0	441	62.6	67.4
57-blue-spotted stingray	*Taeniura lymma*	64.1	221	60.2	68.0
54-blow fishes	Tetraodontidae	64.0	381	61.0	66.9
11-bubble coral	*Plerogyra sp.*	63.1	344	60.1	66.0
14-pineapple coral	Faviidae	62.8	330	60.1	65.5
52-titan triggerfish	*Balistoides viridescens*	59.2	206	55.3	63.2
51-spotted flatheads	Platycephalidae	56.6	66	49.2	64.0
39-glassfishes	Pempheridae	56.2	155	51.2	61.2
Other corals		55.5	465	52.7	58.3
58-manta	*Manta sp.*	54.5	1	–	–
34-squirrelfish	*Sargocentron sp.*	54.4	365	51.6	57.1
40-goatfishes	Mullidae	54.0	329	50.9	57.1
15-black coral	*Antipathes sp.*	51.9	313	48.8	55.1
6-red sea fans	Melithaeidae	51.2	259	47.7	54.7
48-sohal surgeonfish	*Acanthurus sohal*	50.9	201	47.1	54.7

(Continued)

TABLE 4 | Continued

Taxon		Correct identification			
Common name	**Scientific name**	**Mean**	**N**	**95% CI**	
36-blackspotted rubberlip	*Plectorhinchus gaterinus*	50.6	144	45.8	55.4
38-red bass	*Lutjanus bohar*	50.5	310	47.3	53.7
61-dolphins	Delphinidae	49.0	12	28.9	69.1
– sediment covered corals		48.7	330	45.9	51.6
Other bony fishes		46.0	427	43.1	48.9
21-wing oyster	*Pteria sp.*	45.2	235	41.6	48.8
53-boxfishes	Ostraciidae	44.8	160	40.5	49.2
– litter		44.8	284	41.2	48.4
29-spiny starfish	*Acanthaster planci*	42.3	9	21.9	62.7
27-sea cucumbers	Holothuroidea	41.5	77	35.3	47.6
55-porcupinefishes	Diodontidae	39.9	97	34.0	45.8
19-coriacea	*Chromodoris quadricolor*	39.9	61	32.1	47.6
59-torpedo	*Torpedo sp.*	38.0	5	5.1	70.9
other rays and torpedoes		36.0	24	23.3	48.8
26-sea lilies	Crinoidea	34.3	198	30.4	38.3
24-banded boxer shrimp	*Stenopus hispidus*	31.2	29	19.8	42.6
43-longnose hawkfish	*Oxycirrhites typus*	29.1	53	21.8	36.5
28-pearl red star	*Fromia sp.*	27.6	13	13.7	41.4
16-Christmas tree worm	*Spirobranchus sp.*	26.6	177	23.2	30.1
33-needlefishes	Syngnathidae	26.3	68	20.1	32.5
Other cephalopods		25.3	6	4.0	46.7
Other sea slugs		22.7	62	16.7	28.8
30-fire urchin	*Asthenosoma sp.*	21.9	14	8.2	35.6
Other decapods		20.2	49	12.7	27.7
Other sea urchins		18.7	200	15.5	22.0
31-pencil urchin	*Phyllacanthus sp.*	17.9	7	0	41.7
Other bivalves		16.9	151	14.0	19.9
Other starfishes		15.8	32	9.4	22.1
Other sedentary worms		15.3	71	10.5	20.0
17-cowries	Cypraedae	15.1	6	1.1	29.2
25-hermit crabs	Diogenidae	3.8	4	0	11.4

N is the number of trials in which the taxon was present (based on control diver sights).

mean reliability between 50 and 80% (**Supplementary Table 1**; **Figure 2**). Only 23 trials (4.5%) performed with an insufficient level of reliability (α, 95% CI lower bound ≤ 50%); 160 trials (31.2%) scored acceptable relationship with the control diver census (α, 95% CI lower bound > 50% ≤ 60%); 238 trials (46.4%) scored an effective reliability level census (α, 95% CI lower bound > 60% ≤ 70%); 92 trials (17.9%) performed from definitive to very high levels of reliability census (α, 95% CI lower bound > 70% ≤ 100%). Reliability was positively correlated with: team size ($\rho s = 0.212$, $N = 513$, $p < 0.001$, **Table 2**; **Figure 3**), volunteers scores increased with number of present divers, with a score increase of 12.4% between small and big groups (**Table 3**); volunteer diving certification level ($\rho s = 0.200$, $N = 513$, $p < 0.001$,

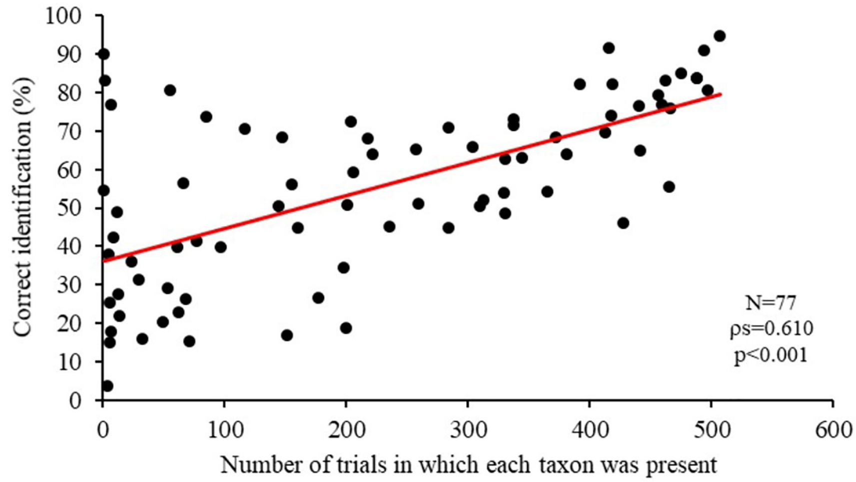

FIGURE 5 | Significant correlation between the percentage of correct identification performed by volunteers (expressed as mean percentage for each taxon) and number of trials in which each taxon was present (based on the control diver sighted). Based on 72 studied taxa, litter presence and sight of damaged corals (see **Table 3**). Indicated in red the trendline of the correlations. N = number analyzed organisms; ρs = Spearman coefficient value.

Table 2; **Figure 4**), volunteers scores increased with higher divers certification level, with an increase of 11.1% between beginners and professional divers (**Table 3**); dive time (ρs = 0.145, $N = 513$, $p < 0.001$, **Table 2**; **Figure 4**), volunteers scores increased with time spent underwater, with an increase of 11.0% between short and long dives (**Table 3**). Reliability was not correlated with date (ρs = 0.029, $N = 513$, $p = 0.515$) and depth (ρs = −0.024, $N = 513$, $p = 0.591$) (**Table 2**).

Distance-based redundancy linear modeling analysis showed that the two variables "diving certification level" and "dive time" comprehensively explained about 82.7% of data variability, while the variable "team size" explained 13% of variability (**Table 5**; **Figure 6**).

DISCUSSION

Notwithstanding the large number of studied species, the accuracy of validation trials was promising, with most trials achieving a mean score between 50 and 70%. As pointed out by correlation and DISTLM analyses, most reliability parameters were positively correlated with the diving certification level, indicating that more experienced divers collected more accurate data. A possible explanation could be that expert divers have major confidence with the diving equipment and their underwater skills in comparison to beginner divers, allowing them focus more on the surrounding environment (Goffredo et al., 2010; Branchini et al., 2015b). Also, the dive time was positively correlated with most reliability parameters, suggesting that longer dives lead to higher data accuracy possibly because divers have more time to look around them and identify organisms.

Two reliability parameters (Accuracy and CAR) showed a positive correlation with the date. Although they are only two of seven parameters, this could suggest that citizen science projects should aim at a long-term duration due to the possibility to improve its implementation through feedbacks from volunteers, thus improving data quality.

Three reliability parameters (CAR, Similarity Index and Reliability) were positively correlated with team size, differently from previous studies where these relationships were not significant (Goffredo et al., 2010; Branchini et al., 2015b). This result could likely be related to presence of big groups belonging to the same diving school, that may be more guided by the instructor while filling in the questionnaire after the dive respect to single independent divers. Moreover, big groups of divers that stay close to each other to prevent the group from dispersing, could survey the marine environment in a more similar way to the control diver compared to small groups in which divers are free to dive. The anonymous data analysis did not allow us to test this aspect.

The lowest score within the analyzed reliability parameters was obtained by the Consistency parameter, with 86.9% of trials with mean consistency between 40 and 70%. This result is in line with previous studies that used the recreational approach and is likely related to the different personal interests of volunteers which made them focus on different species (Branchini et al.,

TABLE 5 | Results of distance-based linear modeling analysis.

Marginal tests				
Variable	**SS**	**Pseudo-F**	**P**	**Prop.**
Date	487.48	1.1263	0.300	2.20E-03
Team size	2595.6	6.0544	0.006	1.17E-02
Diving certification level	11007	26.699	0.001	4.97E-02
Depth	377.51	0.87175	0.381	1.70E-03
Dive time	4336.2	10.196	0.001	1.96E-02

SS = Sum of Squares, P = p-value, Prop. = Proportion of variance explained.

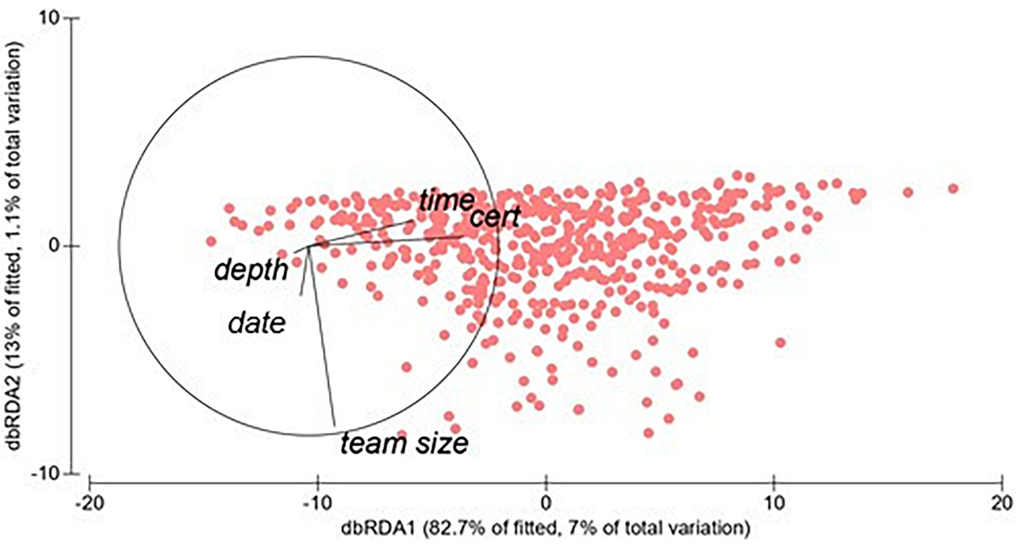

FIGURE 6 | Results of distance-based linear modeling analysis. Variables in the graphs: depth of the scuba diving activity), date of the validation trial, time is the amount of minutes spent underwater, cert is the diving certification level of volunteers and team size is the number of divers present in each validation trial.

2015b). For example, divers interested in macro photography may have focused their attention on small benthic organisms, while others interested in large pelagic fish (e.g., sharks) may have focused their attention away from the reef. Higher consistency results have been found using intensive training program in marine life identification and survey techniques (Mumby et al., 1995; Forrester et al., 2015). While an intense training could increase the consistency of data collected, it will drastically reduce the number of volunteers involved. This could limit the educational role of citizen science projects on volunteers for the lower number of involved volunteers.

The Czekanowski proportional similarity index (SI) showed that volunteers abundance ratings were below the sufficiency threshold in 37.8% validation trials, indicating that volunteers could encounter difficulties in abundance estimation as already found in other studies (Gillett et al., 2012; Done et al., 2017).

The wide variability of mean scores of the Correct Identification parameter could be due to the difficulty for volunteers to see and report the presence of less common or evident taxa (e.g., hermit crab that is frequently found between the rocks and blends in very well), while they performed better in recording the most common, well-known and straightforward species, as previously observed (Goffredo et al., 2010; Cox et al., 2012; Bernard et al., 2013; Branchini et al., 2015b; Forrester et al., 2015; Kosmala et al., 2016).

Previous studies that used the same methodology were performed, respectively, on 38 (Goffredo et al., 2010) and 61 validation trials (Branchini et al., 2015b). This study analyzed 513 validation trials that confirms previous trends permitting to generalize our results. A new result of this study is the team size variable as possible predictor for volunteers data quality, indicating that future data reliability studies should also consider this parameter.

As highlighted by different authors (Lewandowski and Specht, 2015; Kosmala et al., 2016; Specht and Lewandowski, 2018), a limitation of the approach used in this and other studies (Bell, 2007; Oscarson and Calhoun, 2007; Delaney et al., 2008; Aceves-Bueno et al., 2017) is that using professional or expert data, in the case of our study the "control diver," as reference for evaluating volunteer data would also need an evaluation of correctness of the data collected by professionals or experts (Specht and Lewandowski, 2018). In this study control divers were marine biologist of the Marine Science Group trained in the project specifics that spent some weeks monitoring the biodiversity of the surveyed sites, which should assure a good quality of collected data.

In citizen science projects it is fundamental to develop suitable tasks for volunteers to assure good data quality collection (Schmeller et al., 2009; Magurran et al., 2010; Tulloch et al., 2013; Kosmala et al., 2016; Brown and Williams, 2019). In the present study data quality was assured: (1) by asking volunteers to fill the questionnaire soon after the dive, to avoid possible species oversight; (2) by training scuba instructors on the methodology of STE data collection on an annual basis (during public events) or on site when the control diver was present in the diving centers.

Moreover the overall data accuracy of this study was comparable to that performed in other projects by volunteer divers on precise transects (Mumby et al., 1995; Darwall and Dulvy, 1996; Goffredo et al., 2010; Done et al., 2017). This suggest that data from citizen science programs can complement professional datasets with sufficiently accurate data, increasing the possibility of researchers to estimate species richness and providing valuable information on species distributions that are relevant for the detection of the biological consequences of global change (Soroye et al., 2018).

Volunteers quality of data varies with tasks, they perform better at identifying iconic or well-known species while they can be confused by cryptic, rare or unknown specie (Kosmala et al., 2016; Swanson et al., 2016). Some of the methods used to improve the quality of data collected by volunteers are training programs or the request of prequalification via a skill test and the use of ongoing feedback on the volunteers identification for long-term engaged volunteers (Danielsen et al., 2014; Kosmala et al., 2016; van der Wal et al., 2016). Volunteers improve their data accuracy by gaining experience with a project, so a long-term engagement could bring to higher quality of data collected (Weir et al., 2005; Crall et al., 2010; Kelling et al., 2015).

Scuba Tourism for the Environment project was developed in collaboration with several mass tourism facilities and diving centers. During the project, annual meetings with Ministry of Tourism of the Arab Republic of Egypt were carried out to give management and conservation suggestions based on project results.

CONCLUSION

This project provided additional evidence that "recreational" (Goffredo et al., 2004, 2010) and "easy and fun" (Dickinson et al., 2012) citizen science is an efficient and effective method to recruit many volunteers and provide reliable data if well designed (Branchini et al., 2015b). The recreational citizen science approach used in the present study can be exported to different countries and used as a valuable tool by local governments and marine managers to achieve large-scale and long-term data collection, required in a fast-changing world where climate change and anthropogenic pressure on natural resources are leading to fast environmental changes worldwide.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Bioethics Committee of the University of Bologna. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SG, SB, MMe, CM, AM, and EC collected data during the STE project. MMe, MMa, LL, MD, MTr, EN, MTi, RB, SB, PN, and SG analyzed the data. MMe, MMa, CM, EC, FP, AM, SF, and SG wrote the manuscript. SG supervised the research. All authors discussed the results and participated to the scientific discussion.

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SUPPLEMENTARY MATERIAL

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ORIGINAL RESEARCH
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TeaTime4Schools: Using Data Mining Techniques to Model Litter Decomposition in Austrian Urban School Soils

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Litter decomposition plays a pivotal role in the global carbon cycle, but is difficult to measure on a global scale, especially by citizen scientists. Here, citizen scientists, i.e., school students with their teachers, used the globally applied and standardized Tea Bag Index (TBI) method to collect data on litter decomposition in urban areas in Austria. They also sampled soils to investigate the linkages between litter decomposition and soil attributes. For this study, 54 sites were selected from the school experiments and assembled into a TBI dataset comprising litter decomposition rates (*k*), stabilization factors (S), as well as soil and environmental attributes. An extensive pre-processing procedure was applied to the dataset, including attribute selection and discretization of the decomposition rates and stabilization factors into three categories each. Data mining analyses of the TBI data helped reveal trends in litter decomposition. We generated predictive models (classification trees) that identified the soil attributes governing litter decomposition. Classification trees were developed for both of the litter decomposition parameters: decomposition rate (*k*) and stabilization factor (S). The main governing factor for both decomposition rate (*k*) and stabilization factor (S) was the sand content of the soils. The data mining models achieved an accuracy of 54.0 and 66.7% for decomposition rates and stabilization factors, respectively. The data mining results enhance our knowledge about the driving forces of litter decomposition in urban soils, which are underrepresented in soil monitoring schemes. The models are very informative for understanding and describing litter decomposition in urban settings in general. This approach may also further encourage participatory researcher-teacher-student interactions and thus help create an enabling environment for cooperation for further citizen science research in urban school settings.

Keywords: Tea Bag Index (TBI), decomposition rate (*k*), stabilization factor (S), citizen science, knowledge discovery, machine learning, classification trees

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INTRODUCTION

More than 50% of the world's citizens are city dwellers inhabiting urban environments (Seto et al., 2014). These environments may triple in size between 2000 and 2030 if current predictions of urbanization continue (Seto et al., 2012). Accordingly, the closest connection to soils of billions of city dwellers is urban soils, which also represent one of the potential key factors for their wellbeing. Urban soils undergo complex interactions between human populations and the environment while delivering essential functions for society, including climate regulation and habitat for biodiversity (Schulte et al., 2014). At the same time, urban soils face several major challenges due to human influences, i.e., anthropization, including soil sealing, compaction, pollution, heat island effects and loss of biodiversity (Lorenz and Lal, 2009; Guilland et al., 2018). The cycling of carbon in the soil ecosystem, e.g., *via* decomposition, can be altered when humans alter the vegetation structure and composition, leading to changes in above-and below-ground plant litter dynamics (Kaye et al., 2006; Byrne, 2007). Earthworm abundance and biomass also play a role in the decomposer food web (McDonnell et al., 1997). Despite these challenges and the importance of soils for society, for example in terms of carbon sequestration and storage (Edmondson et al., 2012; Churkina, 2016), urban soils have not been extensively studied. A review by Guilland et al. (2018) showed that only 1% of articles on soils between 1960 and 2016 investigated such soils. The most common urban settings for soils are grasslands, street trees and urban forests, urban wastelands, sports grounds, urban gardens of residents or communities and green roofs (Guilland et al., 2018). Human activities on urban soils such as replacement, disturbance, construction of artificial soils, fertilization and pest management make it difficult to monitor as well as assess how they respond to management and land use changes (Lorenz and Lal, 2009, 2017). The urban landscape has been described as a whole new geoscientific sphere, the astysphere (Norra, 2009). Urban soils are often classified as Technosols (IUSS Working Group WRB, 2014), which are characterized by significant amounts of artifacts, i.e., human-made material such as concrete, bricks, sewage sludge and ash. Technosols are often constructed by humans with sometimes careless decisions about what kind of material to put where in the landscape. The global trend of urbanization and the steep increase in city dwellers calls for more research on urban soils to underline their ecological and societal importance in delivering soil functions.

Urban soils and landscapes are ideal for school citizen science, i.e., the participatory generation of new knowledge with school teachers and students (Ryan et al., 2018), based on their close proximity to a large number of schools and teachers. Focusing on the urban environment enables the teachers to take the classes outdoors nearby and to highlight the important functions urban soils deliver to society, including primary productivity. Agriculture and soil science are rarely topics for citizen science projects (Ryan et al., 2018) even though several historical monitoring examples exist (Wildschut, 2017). The importance of agricultural citizen science is increasing in urban settings, where the connections between food systems and consumption are more fragmented than in the countryside. Citizen science fosters bidirectional exchange of information between schools, farmers and researchers, gets students engaged in science through hands-on activities, and enables the students to become active in the democratic processes in their local communities (Ryan et al., 2018). Research partnerships can also have positive impacts on students' science and social skills (Harnik and Ross, 2003), including problem solving, setting working standards and being creative. Using citizen science mobile applications embraces the possibilities of online community building around the respective research theme. This helps foster future collaborations and social networking between citizen scientists themselves or between citizen scientists and researchers in a form that would otherwise not take place (Wildschut, 2017). However, attractive the benefits may sound, teachers still face challenges with outdoor teaching. These include the fact that outdoor teaching has no formal status in the curriculum, the difficulty of getting started and gaining confidence to teach new topics, as well as physical constraints (van Dijk-Wesselius et al., 2020). These challenges can be overcome with the appropriate mindset, determination and curiosity (van Dijk-Wesselius et al., 2020), which should be backed up by superiors. Measuring litter decomposition with the Tea Bag Index (Keuskamp et al., 2013) as part of the teaching curriculum has successfully been used in school settings in Sweden and Austria, with the involvement of motivated teachers (Sandén et al., 2020). Showing teachers that their intelligence, knowledge and creativity are appreciated by and included in the project promotes beneficial participatory cooperation that can be sustained long-term (Wildschut, 2017).

Data mining has been used in all scientific fields to discover new patterns and knowledge from large amounts of data (Trajanov et al., 2018). Its use in citizen science is not new: enormous amounts of data that have been generated through citizen scientist experiments remain to be analyzed and understood (Ceccaroni et al., 2019). Data mining can be used in citizen science in two stages, namely data collection or in analyzing the collected data. When applied during data collection it offers guidance for the planned analyses (e.g., classification tasks), minimizing errors and maximizing data quality (Lukyanenko et al., 2020). When applied to citizen scientist data, it can be used to find causal relationships or patterns in the observations, or to detect biases in the data (Chen and Gomes, 2019). The numerous examples of using data mining in citizen science projects include but are not limited to astronomy, life sciences, environmental sciences and oceanography (Franzen et al., 2021). While citizen science offers enormous opportunities, for example in training classification algorithms, there is also a need for rigorous procedures to ensure data quality (Balázs et al., 2021), as in any scientific research.

This study was designed to predict litter decomposition, i.e., stabilization factors and decomposition rates, and to identify the soil attributes that govern litter decomposition by means of data mining. To this end, we addressed the following questions within the framework of the urban sites investigated by the citizen scientists:

(i) Do the selected soil attributes influence litter decomposition?
(ii) What are the driving factors of litter decomposition in the urban sites investigated by citizen scientists?
(iii) Can data mining help develop reliable predictive models of litter decomposition based on citizen scientists' data?

We hypothesized that soil attributes have a significant influence on litter decomposition and that e.g., soil texture and soil organic carbon are driving the decomposition process. The data mining was expected to give robust predictive models that can be further utilized when studying urban soils, with and without public participation.

MATERIALS AND METHODS

TeaTime4Schools—Citizen Scientist Experiments

An initial call was disseminated in August 2016 to scout interested teachers, followed by a second call in September 2017 to encourage Austrian schools to participate in the TeaTime4Schools[1] activities, i.e., to measure litter decomposition in soils with the help of tea bags. In total, 150 school classes signed up. In April 2018, an interactive workshop was organized for the participating teachers, in which the project tasks including the Tea Bag Index methodology (Keuskamp et al., 2013) were explained and additional information and ideas provided on how to include soils in their curriculum. In May 2018, the teachers received the required materials (a total of 450 pairs of tea bags) by post, along with links to additional video guidance[2] on how to study litter decomposition over a 3-month period (June-September 2018) with their students. The school classes weighed and buried commercially available tea bags (green tea (EAN 87 22700 05552 5) and rooibos (EAN 87 22700 18843 8) produced by Lipton (Unilever) in non-woven polypropylene mesh bags) as miniature litter bags. They were buried pairwise at a depth of 8 cm in the school surroundings, following the standardized Tea Bag Index methodology (Keuskamp et al., 2013). After the tea bags were retrieved in September 2018, they were dried for at least 3 days at a warm, dry location, cleaned of adhering soil particles and re-weighed. Thereafter, the schools classes reported their data directly to the global Tea Bag Index database[3]. Using the mass losses of green tea and rooibos, the TeaTime4Schools researcher team calculated the decomposition rates (k) and the litter stabilization factors (S) according to Keuskamp et al. (2013). Each school class also took one composite soil sample of 10–12 individual soil samples with a spade from 0–10 cm depth at the experimental site in September 2018 and sent it to the researchers for soil analyses (see section "Soil and Environmental Characteristics"). The preliminary results were reported back to the school classes in a final workshop (in presence and online) in March 2019.

Soil and Environmental Characteristics

After arriving in the laboratory, the soil samples were sieved through a 2 mm stainless sieve and air-dried prior to further analyses. Soil pH was measured electrochemically (pH/mV Pocket Meter pH 340i, WTW, Weilheim, Germany) in 0.01 M $CaCl_2$ at a soil-to-solution ratio of 1:5 (ÖNORM L1083). Plant available phosphorous (P) and potassium (K) were determined by calcium-acetate-lactate (CAL) extraction (ÖNORM L1087). Total soil organic C (TOC) concentrations were analyzed by dry combustion in a LECO RC-612 TruMac CN (LECO Corp., St. Joseph, MI, United States) at 650°C (ÖNORM L1080). Total N (N_{tot}) was determined according to ÖNORM L1095 with elemental analysis using a CNS (carbon, nitrogen, sulfur) 2000 SGA-410–06 at 1250°C. $KMnO_4$ determination of labile carbon was analyzed according to Tatzber et al. (2015). Potential nitrogen mineralization was measured by the anaerobic incubation method (Keeney, 1982), as modified according to Kandeler (1993). Texture was determined according to ÖNORM L1061-1 and L1062-2. The environmental characteristics—annual mean air temperature and sum of precipitation for 2018—were taken from the Central Institution for Meteorology and Geodynamics (ZAMG) webpage[4], specifically from their weather stations that were closest to the sampling sites.

Statistical Analyses and Data Mining Methods

As a first step, the statistical analyses of k, S, soil and environmental characteristics were performed using the IBM SPSS Statistics 26 software package. The normality of data was checked with Shapiro-Wilk's test and their descriptive statistics were calculated. Correlations between variables were presented as Pearson correlation coefficients.

As a second step, we used data mining algorithms to model the decomposition rate and stabilization factor from the data obtained from the citizen scientist experiments. In particular, we used algorithms for decision tree induction (Breiman et al., 1984; Witten et al., 2011). Decision trees are predictive models that predict the value of a dependent variable [also called target attribute, in our case decomposition rate (k) and stabilization factor (S)] from a set of independent (descriptive) attributes. They represent a hierarchical structure with a root node, branches and leaf (terminal) nodes. Each internal node contains a test on an attribute in which the value of that attribute is compared to a constant value. The branches coming out of the node represent the outputs of the test. The leaf (terminal) nodes contain the predictions of the target attribute that apply to all samples that fall into that leaf. To predict the value of the target attribute of a new sample, it is routed down the tree according to the values of the outcomes of the tests in each internal node. When the sample reaches a leaf, it is given the prediction assigned to that leaf. Decision trees are generated automatically from data,

[1] https://teatime4schools.at/

[2] https://www.youtube.com/playlist?list=PLR7SjaVR2HuOzcyVGYch5s0ECGMtgPUHc

[3] http://www.teatime4science.org/data/submit-one-data-point/

[4] https://www.zamg.ac.at/cms/de/klima/klimauebersichten/jahrbuch

and the modeler's influence on the structure of the generated model is solely through the settings of the algorithm parameters and is therefore minimal. The attributes that appear in the tree are the ones that carry the most information for predicting the target attribute.

When the values of the target attribute are numeric, the leaves of the decision tree can either contain piece-wise linear regression equations, or constant values that represent the average value of the target attribute of the samples that reach that leaf. In the first case, the decision trees are termed model trees, in the latter case, regression trees. When the values of the target attribute are categorical, the decision trees are termed classification trees.

In this study, the decision trees were obtained using the data mining package WEKA (Witten et al., 2011), which implements a large number of data mining algorithms for different data mining tasks. In particular, we used J48 for induction of classification trees.

Data

The data from the citizen scientist experiments were preprocessed prior to statistical analyses and data mining. Out of the 150 school classes (450 pairs of tea bags) that signed up, 130 (390 pairs of tea bags) partly or fully carried out the project tasks. Out of those, 83 school classes sent soil samples to the TeaTime4School researcher team, and 69 school classes successfully sent soil samples and submitted their results into the global Tea Bag Index database[5]. Here, we focus on data that was sent from urban areas, i.e., artificial surfaces, across Austria (**Figure 1**), altogether from 54 sites (15 sites were filtered out). From each site, data from 1–3 pairs of tea bags (1 green tea, 1 rooibos) were calculated into an average to be used in the data analyses. The schools described their sites as cropland, grassland or forest, but for simplicity, we used the CORINE Land Cover artificial surfaces to extract these sites from our data set. From some of the sites, only data on litter decomposition and environmental characteristics were available due to insufficient amounts of soil sent for analyses. The dataset comprised information about the soil and environmental characteristics described in Section "Soil and Environmental Characteristics" and "Tea Bag Index, Soil and Environmental Characteristics". The decomposition rate (k) and stabilization factor (S) were our dependent variables for which predictive models (model, regression and classification trees) were developed.

In order to strengthen the explanatory power of the data mining results, the values of k and S were discretized into three categories (1, 2 and 3) for each attribute. The discretization was carried out automatically using the discretization filtering method D*iscretize* in the WEKA data mining package, which discretizes a selected attribute into a predefined number of classes. The decomposition rate was discretized into three classes according to the following thresholds: low ($\leq$0.0127 g d^{-1}), medium (0.0127–0.0210 g d^{-1}), high (>0.0210 g d^{-1}). The stabilization factor was discretized into three classes according to the following thresholds: low ($\leq$0.15, medium (0.15–0.29), high (>0.29). The discretization thresholds for both attributes are in accordance with Keuskamp et al. (2013).

In the subsequent step, we recognized annual precipitation and annual temperature and land use that the citizen scientists

[5] http://www.teatime4science.org/

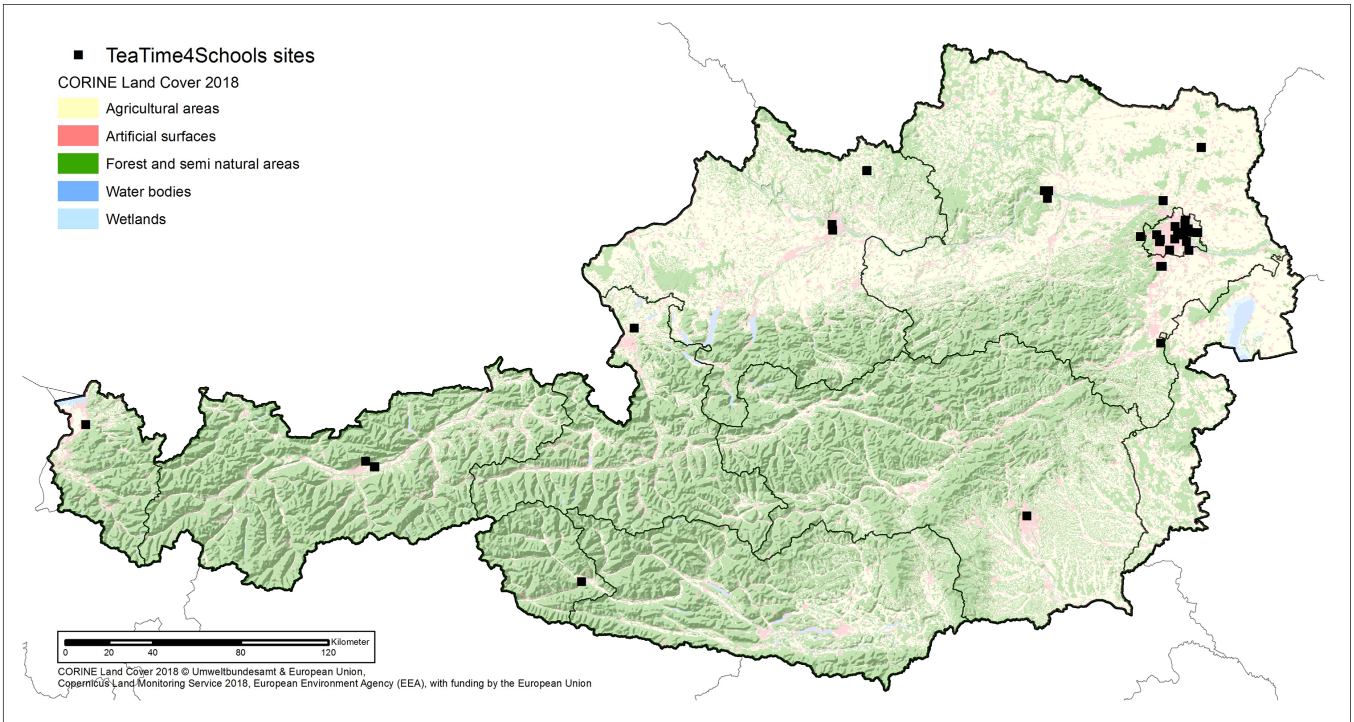

FIGURE 1 | Distribution of urban sites investigated across Austria.

defined as not soil-related attributes and excluded them from the analyses. In addition, we created two scenarios for the data mining analyses in which we used different combinations of attributes. In one scenario, we used detailed information about the soil texture (coarse sand, medium sand, fine sand, coarse silt, medium silt, fine silt), whereas in the second scenario we used aggregated information about the soil texture (sand and silt).

RESULTS

TeaTime4Schools Participation

In total, 130 school classes and at least 2,376 students participated, of which at least 868 were female and 764 male: some school classes did not report the number of students or the number of female and male students. Typical challenges for school classes that failed to complete their tasks were that: (i) the tea bags had disappeared over the course of 3 months, (ii) the tea bags had holes or were otherwise damaged during the experiments, (iii) weighing of the tea bags was unsuccessful due to problems with using the pocket scales (e.g., incorrect unit was used or the final weight exceeded the starting weight), or (iv) the teacher originally involved in the project had changed school class or job and the new teacher could not include the planned activities in her/his curriculum.

Tea Bag Index, Soil and Environmental Characteristics

The decomposition rate (k) ranged between 0.004 and 0.029 g d^{-1}, and the stabilization (S) of the labile fraction of green tea ranged between 0.01 and 0.43 (**Table 1**). The decomposition rate was positively correlated with total annual precipitation ($r^2 = 0.283$, $p < 0.05$) and negatively correlated with mean annual temperature ($r^2 = -0.322$, $p < 0.05$). In addition, positive correlations were found with coarse and middle sand fractions ($r^2 = 0.494$, $p < 0.01$; $r^2 = 0.325$, $p < 0.05$) and negative correlation with the latitude ($r^2 = 0.279$, $p < 0.05$). For stabilization factor, no correlations were found with either decomposition rates, soil attributes or environmental characteristics. Soil pH ranged from acidic 5.16 to alkaline 7.61. A wide range of plant available phosphorous (P) and potassium (K) were observed across the investigated sites, 5.00–763 and 61.0–778 mg kg^{-1}, respectively. TOC ranged between 1.22 and 12.5%, whereas N_{tot} ranged between 0.13 and 1.11%. Moreover, labile carbon and potentially mineralisable N showed large variation between the sites, as did texture (**Table 1**). Mean annual temperature ranged between 9.1 and 13.5°C and total annual precipitation between 552 and 1,345 mm across the investigated sites (**Table 1**).

Data Mining Models for Litter Decomposition

To model the decomposition rate and stabilization factor, we generated four classification trees: one for each dependent variable, k and S, and for each scenario (detailed vs. aggregated soil texture). The accuracy and the root mean squared error of each tree are given in **Table 2** and show a moderate predictive performance. The best classification trees for predicting decomposition rate (k) and stabilization factor (S) were obtained using the aggregated soil texture attributes, which resulted in 54.0 and 66.7% accuracy, respectively. **Figure 2** presents the classification tree for decomposition rate (k) using aggregated soil texture attributes. It indicates the pivotal role of sand content and total nitrogen for decomposition rates. The classification tree for predicting the stabilization factor using aggregated soil texture attributes (**Figure 3**) shows that sand contents as well as plant available potassium and phosphorous played a significant role in stabilizing the labile material.

TABLE 1 | Summary of results for the Tea Bag Index, i.e., decomposition rate (k) and stabilization factor (S), soil and environmental characteristics for the sites investigated in TeaTime4Schools, presented as minimum, maximum and mean (±standard deviation).

	n	Min	Max	Mean (± SD)
k (g d^{-1})	50	0.004	0.029	0.012 (± 0.005)
S	54	0.01	0.43	0.20 (± 0.09)
pH	48	5.16	7.61	7.17 (± 0.41)
P_{CAL} (mg kg^{-1})	48	5.00	763	143 (± 167)
K_{CAL} (mg kg^{-1})	48	61.0	778	253 (± 176)
TOC (%)	48	1.22	12.5	4.53 (± 2.68)
N_{tot} (%)	48	0.13	1.11	0.37 (± 0.21)
C/N	48	9.40	18.4	12.2 (± 1.97)
Labile C (mg kg^{-1})	47	414	1426	910 (± 254)
Potentially mineralisable N (mg kg^{-1} 7 d^{-1})	48	36.8	350	168 (± 78)
Sand (%)	39	13.7	65.9	35.4 (± 10.9)
Silt (%)	39	26.6	64.6	42.3 (± 8.3)
Clay (%)	39	5.40	42.5	22.3 (± 8.8)
Annual mean air temperature in 2018 (°C)	54	9.10	13.5	11.6 (± 0.9)
Annual sum of precipitation in 2018 (mm)	54	552	1345	697 (± 141)

DISCUSSION

Litter Decomposition

Our results support both previous global (Keuskamp et al., 2013) and local (Sandén et al., 2020) studies on litter decomposition based on the Tea Bag Index methodology. The decomposition rates we calculated were similar to those reported for the Pannonian environmental zone by Sandén et al. (2020), which reflects the fact that most of our present sites are in the Pannonian environmental zone. The stabilization factors were somewhat higher, 0.20 compared to 0.14, than for the Pannonian environmental zone in Sandén et al. (2020), possibly due to the nature of urban soils in our study compared to croplands, grasslands and forests in the other study. Interestingly, our results on stabilization factors agree well with Duddigan et al. (2020) who studied Tea Bag Index in domestic gardens in the United Kingdom, even though the climatic factors were quite different to our sites. Fung et al. (2021) recently reported on litter decomposition using Tea Bag Index in urban Singapore soils and Tresch et al. (2018) from urban gardens in Switzerland, however, they did not calculate the decomposition rates and

TABLE 2 | Predictive performance (accuracy and RMSE) of the four classification trees generated for modeling decomposition rate and stabilization factor.

		Decomposition rate (k)		Stabilization factor (S)	
		Accuracy	RMSE	Accuracy	RMSE
Scenario 1	Detailed soil texture (coarse/medium/fine sand, coarse/medium/fine silt, and clay)	48.0%	0.50	55.5%	0.44
Scenario 2	Aggregated soil texture (sand, silt, and clay)	54.0%	0.46	66.7%	0.41

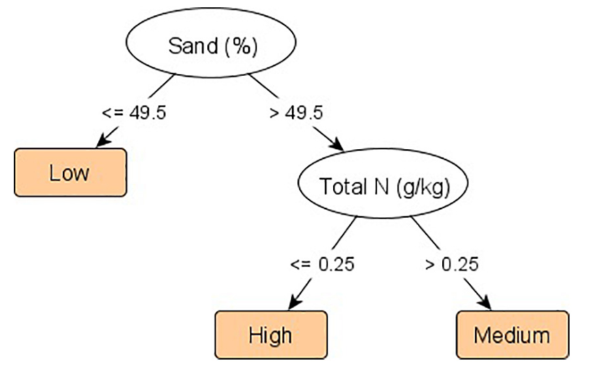

FIGURE 2 | Classification tree for predicting decomposition rate (*k*). Low represent values (≤0.0127 g d–1), medium values (0.0127–0.0210 g d–1), and high values (>0.0210 g d–1).

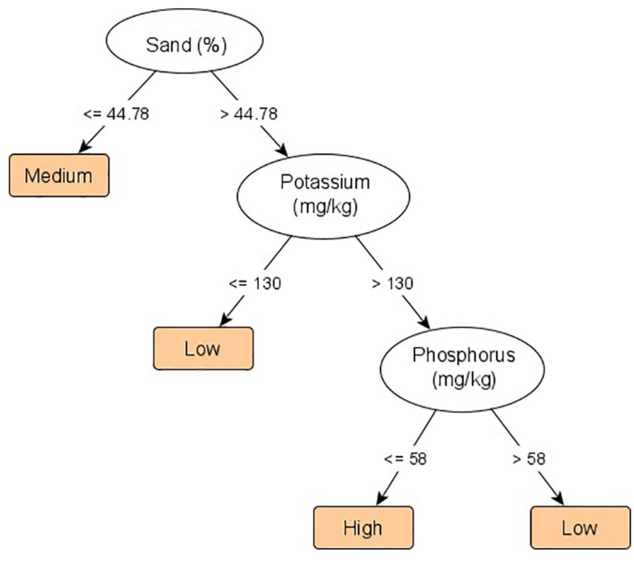

FIGURE 3 | Classification tree for predicting stabilization factor (S). Low represent values (≤0.15), medium values (0.15–0.29), and high values (>0.29).

stabilization factors, but only presented the total mass losses over the burial time that makes comparison of results more difficult. Litter decomposition dynamics in urban soils may be hampered or accelerated because the decomposer community may be disrupted or their microhabitat destroyed (Byrne, 2007). Moreover, the burial of topsoil decomposers or exposure of subsoil decomposers to topsoil conditions (Craul, 1999) due to mechanical soil mixing might explain the different decomposition dynamics. Soil pH changes due to the human influence on urban soils may also affect decomposer communities (Beyer et al., 1995). showed that urbanization may affect decomposition by altering leaf litter quality. They investigated decomposition of five different litters and found that the local litter was decomposing fastest in urban areas (Dorendorf et al., 2015). This can be explained by the home-field advantage (HFA) hypothesis that has been shown in many environments, and estimated to contribute to about 7.5% faster decomposition at the site where the litter originates compared to other litters on a global scale (Veen et al., 2015). In our case, the litter, i.e., green tea and rooibos, are the same in each study site and therefore comparisons between urban and rural areas would be easy to conduct. To get a better overview of differences between Tea Bag Index in urban and rural soils, further data collection from both urban and rural areas should be undertaken. A possible example for how to collect further data in rural areas could be to utilize the Long Term Socio-Ecological Research platforms (LTSER), as has been done in France (Bretagnolle et al., 2018).

The main governing factor for both decomposition rate and stabilization factor was the sand content of the soils according to our data mining models (**Figures 2**, **3**). Soil texture is known to influence decomposition in many ways, including its effects on soil water dynamics, nutrient availability and pore size distribution. Note, however, that its influence on decomposition may sometimes be shown only in combination with its effects on soil water pressure, as in Scott et al. (1996), or not be evident at all as in McLauchlan (2006). Many modeling approaches of soil organic matter dynamics such as century (Parton et al., 1987) or RothC (Jenkinson et al., 1990) focus on silt and clay contents instead of the sand content of the soil. In our case, higher decomposition rates at increased sand contents (>49.5%) may be attributable to suitable pore size distribution for soil microbes to move and to distribute microbial substrates (Scott et al., 1996). One reason why clay content did not appear as an important factor for stabilization in our decision trees could be the time aspect; the tea bags were buried in the soil for only 3 months, which is an ideal timeframe for studying the initial decomposition dynamics. These may likely be more influenced by the sand than by the clay content.

Another important driver for decomposition rates was total nitrogen (**Figure 2**). The importance of plant available potassium and phosphorous became evident in the model created for the stabilization factor (**Figure 3**); that model shows that, even in urban areas, fertilization affects soil biochemical cycles (Lorenz and Lal, 2009). The stabilization factor was higher at low to medium phosphorous contents up to 58 mg kg^{-1}, whereas for potassium at least 130 mg kg^{-1} was needed for higher stabilization factors. Both values of plant available nutrients represent sufficient levels for productivity for grasslands and croplands in Austria (BMLFUW, 2017).

Future Potentials and Trends

The barriers between science and the public (Wildschut, 2017) can be opened by showing that citizen scientists' data are a very valuable contribution to science. This is especially true when important patterns are revealed by data mining. Ryan et al. (2018) described the benefits of technology for citizen science as a way to convert data into usable information. This is precisely what data mining can do for data collected by citizen scientists. Such data mining poses both challenges and opportunities (Franzen et al., 2021). In this era of digitalization and an increasingly data-oriented society, the use of data mining to understand, analyze and obtain new knowledge is inevitable. Importantly, applying data mining methods to citizen science data requires caution to avoid potential bias and counter the varying quality of the data. The benefits and opportunities of this approach clearly outweigh the challenges. Our study, by applying data mining and generating predictive models from the Tea Bag Index data, has set the basis for creating educational materials for schools about the importance of analyzing urban soils. This sets the framework for planning experiments in order to collect more data and improving the experimental setup in order to obtain wider coverage on regional or national scales. Despite the modest predictive performance of the created models, they are informative for understanding and describing litter decomposition in urban settings where very little data exist (Guilland et al., 2018). To improve the models, the most important task is to collect more data on the Tea Bag Index and on the soil attributes governing litter decomposition. This includes at least soil texture (sand, silt, clay contents), total nitrogen and plant-available phosphorous and potassium.

Showing the results of the analyses to and discussing them with the citizen scientists, i.e., the participating teachers and students, showcases the importance of their involvement in scientific knowledge creation. This is a major motivating factor for their future involvement in similar citizen science projects and may even help inspire careers in science. By sharing our results in social media and through our school network connections, we expect our results to encourage citizen scientists to question the natural phenomena of litter decomposition and its connection to the global carbon cycle. We hope this motivates them to continue their discoveries on their own or in cooperation with us. Previous research has shown that a brief training of citizen scientists may not increase science literacy or overall attitudes (Crall et al., 2013). We therefore aim at several interaction points with the teachers and students to foster future engagement in environmental issues. If a teacher or student is seen as an opinion leader, that person may be able to motivate others to change their personal behavior toward a more environmentally friendly lifestyle (Nisbet and Kotcher, 2009). This multiplies the knowledge gained through their participation. We aim to help citizen scientists understand that the predictive performance of the created models—and of any models—can only be as good as the data behind them, and that better models may require more data, more citizen scientists and/or even more precise data.

Through litter decomposition experiments we aim to generate new knowledge, create learning opportunities for both scientists and citizen scientists, and enable civic participation in science—three aspects that were highlighted as innovation potentials of citizen science by Turrini et al. (2018). In order to make it simpler for new citizen scientists to participate and to enable previous participants to continue their discoveries with new categories of soil characterizations, the Tea Bag Index App was created and launched in 2019, in cooperation with agricultural high school students and their teacher[6]. This approach promotes long-term engagement of citizen scientists, motivating them to remain active and communicate with other citizen scientists on the Tea Bag Index App or other citizen science Apps running on the same Spotteron Platform[7]. We envision that this will increase the value of the precious time that the citizen scientists devote and that we essentially borrow for scientific purposes (Ryan et al., 2018). Such cooperation may lead to long-lasting collaborations in which important knowledge networks, as are becoming increasingly common in agriculture (Baumgart-Getz et al., 2012), are being created and science is being done for the people, by the people.

CONCLUSION

Our study successfully created new scientific knowledge on litter decomposition, i.e., decomposition rates (k) and stabilization factors (S), in cooperation with school students. This approach created new soil science learning opportunities for students in cooperation with their teachers. The most important factor for both k and S was the sand content of the soils. The decomposition rates were also affected by total nitrogen contents of the soils, whereas the stabilization factor was additionally governed by plant-available potassium and phosphorous. We generated data mining models for decomposition rate (k) and stabilization factor (S) from citizen-scientist-collected Tea Bag Index (TBI) data that are representative for poorly studied urban soils. The predictive performance of the generated models, 54.0 and 66.7% for k and S, respectively, could further be improved by additional data collection and subsequent data mining, as is planned with the newly launched Tea Bag Index App. Future discussions about the generated models in the framework of school workshops will be a next major step in connecting citizen scientists with the results and promoting conversations about the driving factors of decomposition dynamics. This is aimed at establishing a long-term participatory cooperation in which citizen scientists and researchers learn from one another and new ground will be broken in participatory citizen soil science.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. The data will be included in the TBI database that will be published online on www.teatime4science.org after publication of global results. Until publication on this platform, the data can be obtained by emailing TS, taru.sanden@ages.at.

[6]https://teatime4schools.at/en/teatime4app/

[7]https://www.spotteron.net/de/citizen-science-apps

AUTHOR CONTRIBUTIONS

TS, AW, HB, JM, AS, BG, and HS were mainly responsible for the generation of the dataset with the help of citizen scientists. AT and MD were mainly responsible for the data mining and the analyses of those results. TS and AT did most of the writing. All authors contributed to the manuscript revision, read, and approved the submitted version.

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The Effect of Animal Bipedal Posture on Perceived Cuteness, Fear, and Willingness to Protect Them

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Human–animal relationships have long been the subject of controversy because they are shaped by several cultural, inter-individual, and evolutionary factors. Understanding these relationships, however, is important to optimize conservation efforts. There is agreement that perceived similarity between animals and humans is associated with more positive attitudes. The human–animal similarity could be caused by phylogenetic closeness. We hypothesized that the bipedal posture of an animal may be perceived as a cue of phenotypic similarity with humans. We examined this topic by comparing perceived cuteness, fear, and willingness to protect animals differing in body posture, body size, and phylogenetic closeness with humans on a sample of *N* = 349 Slovak participants. We found that the bipedal posture enhanced perceived cuteness, but this effect was most pronounced in small-bodied animals, particularly those with direct eye contact. Phylogenetically close and small-bodied species (e.g., small mammals) received greater conservation support than phylogenetically distant species (e.g., invertebrates). However, anthropomorphic-looking animals received greater conservation support, suggesting that pictures of animals that more closely resemble humans can be used in conservation campaigns.

Keywords: bipedal posture, animals, attitudes, conservation, willingness to protect

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INTRODUCTION

We are not seeing animals as animals, but merely as reflections of ourselves, and if the mirror distorts too badly, we either bend it into shape or discard it.

Morris (1969, p. 200)

The complexity of human–animal relationships is the subject of controversy (Mullin, 1999) because animal roles in human lives are multidimensional (Kellert, 1980, 1983, 1993; Serpell, 2004). Throughout our evolutionary history, animals have been predators of our ancestors (Hart and Sussman, 2008), important sources of food (Ungar and Teaford, 2002), and vectors of zoonotic diseases (Kruse et al., 2004). Since the beginning of the Neolithic era, many animals have been treated as companions (Podberscek et al., 2005), with others being agricultural pests (Ordish, 1976). The enormous diversity of animal shapes, sizes, and behaviors heavily contributes to human evaluations of them (Serpell, 2004). Human preferences are of interest to conservationists because the low popularity of an animal, regardless of why it occurs, erodes public support for its conservation (Kellert, 1985; Houston et al., 2010; MacFarlane and Rocha, 2020).

Human activities contribute to the global loss of biodiversity comparable with the five previous mass extinctions of Earth's history (Barnosky et al., 2011; Dirzo et al., 2014). More than 400 vertebrates became extinct since 1500 (IUCN, 2020). Although invertebrates received much less attention than vertebrates, their extinction rates seem to be similar. For instance, insect abundance in protected natural areas in Germany dropped by 75% over the last 27 years (Hallmann et al., 2017), and roughly 50% of butterfly species (Lepidoptera) were extirpated in Singapore since 1854 (Theng et al., 2020). The reduction of biodiversity can negatively influence ecosystem functioning and human wellbeing by means of disease spread, climate change, and decreased farm productivity (Newbold et al., 2019; van der Plas, 2019). Because all animals play important roles in ecosystems, it is necessary to investigate the factors underlying their preferences by the general public in order to make conservation more effective (Frynta et al., 2013).

The willingness of people to protect animals is influenced by a complex interplay between emotions and attitudes toward them (Castillo-Huitrón et al., 2020), resulting in non-random preferences for certain species (Driscoll, 1995; Bjerke and Østdahl, 2004; Frynta et al., 2013; Borgi and Cirulli, 2015; Prokop and Randler, 2018). Humans prioritize esthetically appealing animals (Serpell, 2004) characterized by bright colors (Marešová et al., 2009; Barua et al., 2012; Prokop and Fančovičová, 2013; Curtin and Papworth, 2020), large body size (Frynta et al., 2010; Knegtering et al., 2010; Smith et al., 2012; Macdonald et al., 2015; Curtin and Papworth, 2020), and with a non-aggressive appearance (Prokop and Fančovičová, 2017). Furthermore, these preferences are similar across genders (Prokop and Fančovičová, 2013).

Preferences for some animals over others are noteworthy because the perceived attractiveness of an animal species can be an important determinant of conservation support (Gunnthorsdottir, 2001; Tisdell et al., 2006; Martín-López et al., 2007; Knight, 2008; Wang et al., 2018; Curtin and Papworth, 2020). For instance, more popular species at the Paris Zoological Park can receive 46 times the funds of less popular species (Colléony et al., 2017).

Animals that are cognitively, behaviorally, physically, or phylogenetically similar to humans are perceived by humans in a more positive light than distant or dissimilar animals (Plous, 1993; Allen et al., 2002; Knight et al., 2003; Serpell, 2004). Humans express increased empathy and compassion with decreasing phylogenetic distance from humans (Miralles et al., 2019). It has been shown that our perception of "the others" may depend on the group to which we perceive that "the others" belong, that is, the more we perceive the members of the other person/group in need as being similar to us, the more we value their welfare (e.g., Batson, 2011). Małecki et al. (2020) found that the subjective perception of the level of kinship between humans and animals depicted in a narration had a significant influence on the improvement of attitudes toward animal welfare. However, the objective measure of the phylogenetic distance was not related to any changes in attitudes toward animal welfare.

Another largely overlooked cue of species similarity with humans is bipedal posture. Morris (1969) argues that the popularity of penguins, primates, bears, pandas, or dogs is significantly influenced by their ability to stand vertically because animals in bipedal postures resemble humans more than in quadrupedal postures. As far as we are aware, no research has investigated the degree to which the bipedal posture of an animal influences human perceptions and attitudes. We postulate that perceived cuteness, fear of animals, and willingness to protect animals would be worthwhile to investigate because these variables are related to the psychological aspects of animal conservation (Prokop and Fančovičová, 2013; Castillo-Huitrón et al., 2020).

We hypothesized that animals with bipedal posture would be perceived as cuter (and thus more likely to induce human willingness to protect them) than animals with quadrupedal posture. We also hypothesized that large animals would be perceived as more dangerous than small animals (Prokop et al., 2010; Staňková et al., 2021). Thus, the perceived cuteness of small animals in bipedal posture should be greater than the perceived cuteness of large animals in bipedal posture. Furthermore, we hypothesized that phylogenetically distant animals would be perceived as less cute than phylogenetically close animals (Miralles et al., 2019). Finally, both bipedal posture and phylogenetical closeness should be associated with a greater willingness to protect animals.

MATERIALS AND METHODS

Participants

The research was carried out during the summer semester of 2020. Roughly 1,500 freshman students at a university in Slovakia were asked to voluntarily participate in the research. Furthermore, the participants were recruited through social networks. A total of 349 participants (272 females) comprised the final sample (age range = 18–67 years, mean = 25, SE = 0.45; **Table 1**).

Measurement of Cuteness, Perceived Fear, and Willingness to Protect Animals

The participants were asked to rate 52 pictures of 26 animal species for cuteness, perceived fear, and willingness to protect these animals on a seven-point scale (e.g., 1 = not at all cute, 7 = extremely cute). The ratings showed excellent reliabilities (Cronbach α = 0.97, 0.97, and 0.98, respectively).

Measurement of Phylogenetic Distance From Humans

The phylogenetic divergence time from humans (in millions of years) was obtained for each species from timetree.org (Kumar et al., 2017).

TABLE 1 | Descriptive statistics for cuteness, fear, and willingness to protection ratings of animals.

Parameter		Cuteness		Fear		Willing to protection		N
		Mean	CI	Mean	CI	Mean	CI	
Gender	Male	4.11	4.05–4.18	2.63	2.58–2.69	5.06	5.00–5.12	4,004
	Female	4.03	4.00–4.07	3.22	3.19–3.25	4.97	4.94–5.00	14,144
Anthropomorphy	No	3.85	3.82–3.89	3	2.97–3.04	4.87	4.83–4.90	12,913
	Yes	4.53	4.48–4.59	3.3	3.25–3.36	5.29	5.24–5.34	5,235
Bipedal posture	Yes	4.06	4.02–4.11	3.11	3.07–3.15	4.97	4.93–5.01	9,074
	No	4.04	3.99–4.08	3.07	3.03–3.11	5.01	4.97–5.05	9,074
Eye contact	No	4.05	4.02–4.09	2.96	2.92–2.99	4.95	4.91–4.98	13,611
	Yes	4.04	3.98–4.11	3.5	3.44–3.56	5.12	5.07–5.17	4,537
Size	Large	3.84	3.80–3.89	3.65	3.61–3.70	5.08	5.04–5.12	8,725
	Small	4.24	4.20–4.29	2.57	2.54–2.61	4.9	4.86–4.94	9,423

TABLE 2 | List of species used in the research.

Scientific classification	Large species	Small species
Vertebrates		
Primates	Western lowland gorilla (*Gorilla gorilla*)	Ring-tailed lemur (*Lemur catta*)
Carnivora	American black bear (*Ursus americanus*)	Meerkat (*Suricata suricatta*)
Marsupialia	Red kangaroo (*Macropus rufus*)	Rufous hare-wallaby (*Lagorchestes hirsutus*)
Rodentia	Capybara (*Hydrochoerus hydrochaeris*)	Ground squirrels (*Spermophillus citellus*)
Pilosa	Southern tamandua (*Tamandua tetradactyla*)	Silky anteater (*Cyclopes didactylus*)
Pholidota	Giant pangolin (*Smutsia gigantea*)	Philippine pangolin (*Manis culionensis*)
Reptilia	Komodo dragon (*Varanus komodensis*)	Common basilisk (*Basiliscus basiliscus*)
Invertebrates		
Hymenoptera	Carpenter ant (*Camponotus flavomarginatus*)	Yellow crazy ant (*Anoplolepis gracilipes*)
Phasmoptera	Malagasy blue stick insects (*Achriptera fallax*)	Laboratory stick insect (*Carasius morosus*)
Decapoda	Christmas Island red crab (*Gecarcoidea natalis*)	Blue crab (*Calinectes sapidus*)
Gastropoda	Roman snail (*Helix pomatia*)	White-lipped snail (*Cepaea hortensis*)
Matodea	Devil flower mantis (*Idolomantis diabolica*)	Orchid mantis (*Hymenopus coronatus*)
Myriapoda	Giant millipede (*Spirostreptus* sp.)	Black millipede (*Tachypodiolus niger*)

Each species was represented by two pictures: quadrupedal and bipedal.

Measurement of Direct Eye Contact

Animals on pictures were scored binomially (yes or no) according to direct or indirect eye contact. This procedure was used because it was not possible to obtain pictures of all animals with a standard gaze. This variable could be important because direct eye contact is a signal of potential threat (Emery, 2000).

Measurement of Anthropomorphism

Animals which looked like humans by their posture or activity (e.g., a basilisk running on the surface of water) were binomially classified as anthropomorphic or not. Two of us separately and independently scored the pictures for anthropomorphism. In the few cases where our scorings differed, we discussed the pictures of animals until we agreed on the score to be awarded. Anthropomorphism, in this sense, was not always associated with bipedal posture (e.g., standing Komodo dragon), and we therefore considered it as an additional independent variable.

Visual Stimuli

Colorful pictures, with their original background, of 14 vertebrate and 12 invertebrate species which at least occasionally use bipedal posture were downloaded from Google. The species were further selected according to their phylogenetical similarity and body size (**Table 2**). We used two pictures for each species: one in bipedal posture and one in quadrupedal posture. Throughout the paper, we used the term quadrupedal also for invertebrates with more than four legs. For invertebrates, pictures of bipedal animals were searched using common English or Latin names together with the word “bipedal” or “standing.” Birds were completely omitted because they are invariably bipedal.

Statistical Analyses

The cuteness, fear, and protection scores were defined as dependent variables in a cumulative link mixed model (CLMM) in R software 3.6.3 (R Core Team, 2019) by applying the clmm function in an ordinal package (Christensen, 2019). Bipedal posture (bipedal or quadrupedal), anthropomorphic (yes or no), eye contact (yes or no), body size (large or small), and gender of the participant were categorical predictors, whereas phylogeny was a continuous predictor (fixed effects). The identity of the participants and the species of animal in the pictures were used as a grouping factor (random effects) to deal with correlations within the participant ratings. To select the particular factor, stepwise selection was used and evaluated by the Akaike information criterion (AIC). The syntax of the final CLMM models are as follows:

Cute.score ∼ Phylogeny + Anthropomorphy + Eye.contact + Biped + Gender + Size + Phylogeny:Gender + Phylogeny: Biped + Anthropomorphy:Eye.contact + Size:Gender + Size: Phylogeny + Eye.contact:Size + Anthropomorphy:Size + Size: Biped + (1 | ID.participant) + (1 | ID.species).

Protection ∼ Phylogeny + Anthropomorphy + Biped + Size + Size:Biped + Anthropomorphy:Phylogeny + (1| ID respondent) + (1| ID.species).

Fear ∼ Phylogeny + Anthropomorphy + Eye contact + Biped + Gender + Size + Phylogeny:Size + Phylogeny: Gender + Eye contact:Biped + Size:Gender + Biped:Phylogeny + (1| ID.respondent) + (1| ID.species).

RESULTS

The best CLMM models for cuteness and fear ratings contain six fixed effects (phylogeny, anthropomorphy, bipedal posture, size, eye contact, and gender) and numerous interactive effects (eight for cuteness and five for fear; **Tables 3**, **4**). In the case of the protection rating model, four fixed factors and two interactions were included (**Table 5**). The final CLMM model values of log likelihood ratio, AIC, and marginal, conditional, and pseudo r-squared are shown in **Table 6**. The likelihood ratio test showed the random effects, which have been included in all the CLMM models, to be significant ($p < 0.001$).

Bipedal Posture

Animals with bipedal posture were rated as significantly less cute than animals with quadrupedal posture (**Figure 1A**). However, the combination of bipedal posture with other variables increased the perceived cuteness to a greater degree—for example, bipedals that are small in size were considered to be significantly cuter than larger ones (**Figure 2A**). Additionally, high cuteness scores were specifically associated with animals in bipedal posture that are phylogenetically closer to humans (e.g., bipedal mammals; **Table 3**).

Animals with bipedal posture received higher fear scores than animals with quadrupedal posture (**Figure 1B**). Interactive effects revealed that quadrupedal animals with direct eye contact were considered more menacing than other combinations of these factors (**Table 4**). Higher fear scores were associated with animals in bipedal posture that are phylogenetically close to humans, such as bipedal mammals (**Table 4**).

When considering the factor of bipedalism regarding willingness to protect, people were generally more willing to protect quadrupedal animals than animals with bipedal posture (**Figure 1C**). Animal size moderated this effect, such that willingness to protect was strongest toward small animals in bipedal posture (**Figure 2B**).

Phylogeny

The factor of phylogeny was very strong when assessing all dependent variables (cuteness, fear, and willingness to protect; **Tables 3–5**). Animals phylogenetically closer to humans (e.g., mammals) were perceived as cuter than phylogenetically distant animals (e.g., insects; **Figure 3A**). Small animals phylogenetically distant from human (e.g., small insects) received lower cuteness

TABLE 3 | Results of the cumulative link mixed model on the respondent's cuteness ratings.

	Estimate	Variance	SD	Lower CI	Upper CI	Odds ratio	z-value	P
Fixed effect terms								
Phylogeny	−1.59			−2.63	−0.55	0.204	−2.998	0.003
Anthropomorphy-yes	0.576			0.344	0.809	1.779	4.863	<0.001
Eye contact-yes	−0.575			−0.783	−0.366	0.563	−5.393	<0.001
Biped-no	0.389			0.213	0.564	1.475	4.335	<0.001
Gender-female	0.242			−0.198	0.682	1.274	1.078	0.282
Size-small	1.612			0.456	2.768	5.012	2.733	0.007
Phylogeny/gender	−0.801			−0.956	−0.645	0.449	−10.091	<0.001
Phylogeny/biped	−0.355			−0.52	−0.189	0.701	−4.193	<0.001
Anthropomorphy/eye contact	0.406			0.168	0.644	1.501	3.339	<0.001
Gender/size	0.231			0.101	0.361	1.26	3.478	<0.001
Phylogeny/size	−1.634			−2.837	−0.43	0.195	−2.661	0.008
Eye contact/size	0.23			−0.013	0.473	1.258	1.854	0.064
Anthropomorphy/size	−0.459			−0.695	−0.222	0.632	−3.801	<0.001
Biped/size	−0.257			−0.451	−0.063	0.774	−2.591	0.01
Random effect terms								
ID respondent		2.786	1.669					<0.001[a]
IDspecies		0.832	0.912					<0.001[a]

Biped, bipedal posture.
[a]*Likelihood ratio tests of cumulative link models.*

TABLE 4 | Results of the cumulative link mixed model on the respondent's fear ratings.

	Estimate	Variance	SD	Lower CI	Upper CI	Odds ratio	*z*-value	*P*
Fixed effect terms								
Phylogeny	−3.104			−4.741	−1.468	0.045	−3.718	<0.001
Anthropomorphy-yes	−0.239			−0.376	−0.103	0.787	−3.443	<0.001
Eye contact-yes	0.262			0.143	0.38	1.299	4.33	<0.001
Biped-no	−0.215			−0.368	−0.062	0.806	−2.758	0.006
Gender-female	0.689			0.253	1.125	1.992	3.099	0.002
Size-small	−3.206			−5.045	−1.367	0.041	−3.417	<0.001
Phylogeny/size	3.036			1.162	4.91	20.822	3.176	0.002
Phylogeny/gender	0.441			0.276	0.607	1.555	5.229	<0.001
Eye contact/biped	0.459			0.17	0.747	1.582	3.118	0.002
Gender/size	0.198			0.058	0.338	1.219	2.775	0.006
Phylogeny/biped	0.164			0.005	0.323	1.178	2.017	0.044
Random effect terms								
ID respondent		2.707	1.645					<0.001[a]
IDspecies		2.186	1.479					<0.001[a]

Biped, bipedal posture.
[a]Likelihood ratio tests of cumulative link models.

TABLE 5 | Results of the cumulative link mixed model on the respondent's willing to protection ratings.

	Estimate	Variance	SD	Lower CI	Upper CI	Odds ratio	*z*-value	*P*
Fixed effect terms								
Phylogeny-yes	−2.422			−3.201	−1.643	0.089	−2.998	<0.001
Anthropomorphy-yes	0.199			0.06	0.338	1.22	4.863	0.005
Biped-no	0.227			0.124	0.329	1.255	−5.393	<0.001
Size-small	0.341			0.027	0.656	1.407	4.335	0.034
Biped/size	−0.199			−0.317	−0.08	0.82	1.078	0.002
Phylogeny/anthropomorphy	−0.295			−0.51	−0.081	0.744	2.733	0.007
Random effect terms								
ID respondent		6.183	2.4866					<0.001[a]
IDspecies		0.7307	0.8548					<0.001

Biped, bipedal posture.
[a]Likelihood ratio tests of cumulative link models.

scores (**Figure 3B**). When rated by women, phylogenetically distant animals received significantly lower cuteness scores relative to the ratings provided by men (**Table 3**).

Phylogenetically close animals were associated with higher fear scores when compared to phylogenetically distant animals (**Figure 3A**). The interaction terms showed that the fear scores were highest when considering animals phylogenetically close to humans and displaying a bipedal posture (e.g., mammals in bipedal posture; **Table 4**).

TABLE 6 | Log Likelihood-ratio, Akaike information criterion, marginal, and conditional r-squared values of cumulative link mixed models.

Value/model	Cuteness	Fear	Protection
Log likelihood ratio	–26,981	–25,530	–24,393
Akaike information criterion	54,007	51,098	48,813
Conditional R-squared	0.645	0.655	0.710
Marginal R-squared	0.255	0.141	0.101

Phylogeny significantly affected the willingness to protect animals. People were willing to protect animals phylogenetically close to humans, such as mammals (**Figure 3A**), especially when it comes to small mammals (**Table 5**). The lowest protection scores were for animals that are phylogenetically distant from humans but looked anthropomorphic (e.g., insect with raised front legs; **Table 5**).

Anthropomorphism

Animals resembling humans in terms of posture or activity (e.g., a bipedally running reptile or standing gorilla) were perceived as cute (**Figure 4A**). Moreover, small animals resembling humans were evaluated as cuter than large anthropomorphic animals (**Table 3**). High cuteness scores were assigned to small anthropomorphic-looking animals with direct eye contact (**Table 3**).

In general, the respondents were not afraid of animals that looked anthropomorphic (lower fear scores; **Figure 4B**) and were willing to protect them (anthropomorphism increases the

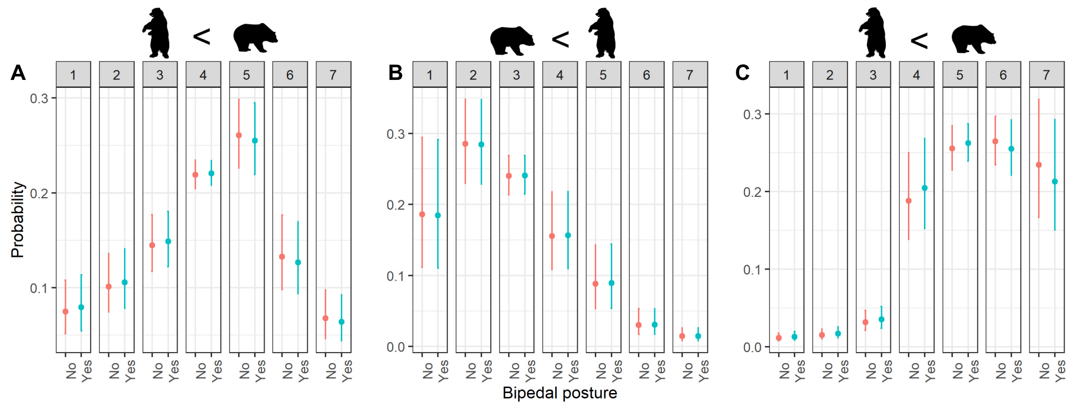

FIGURE 1 | Estimated probability of ratings for **(A)** cuteness, **(B)** fear, and **(C)** willingness to protection according to Bipedal posture. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

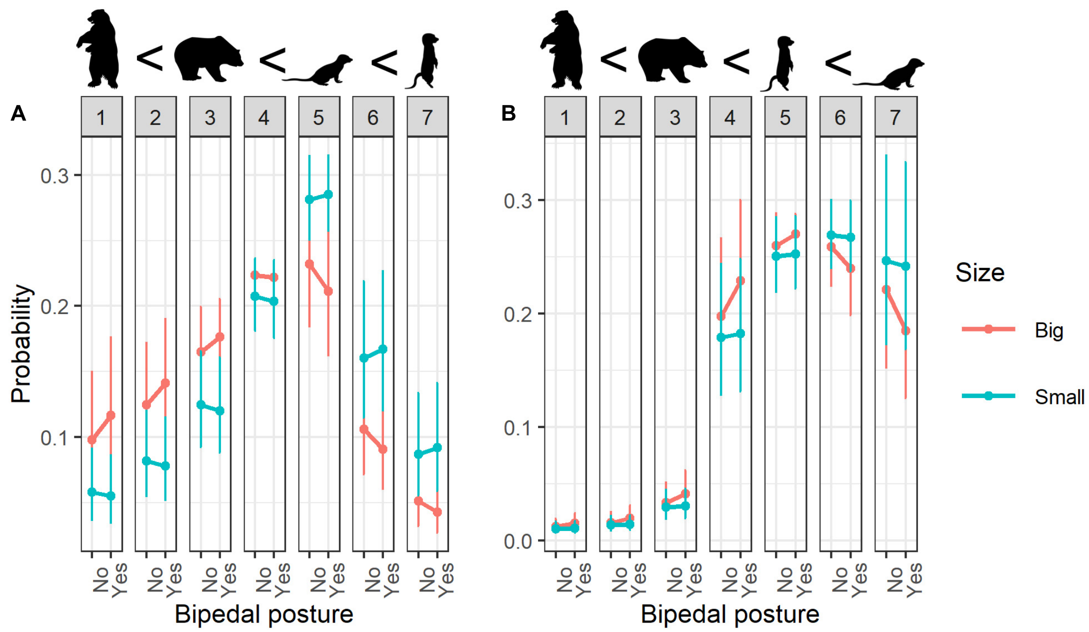

FIGURE 2 | Interaction effects of Bipedal posture:Size for **(A)** cuteness, **(B)** willingness to protection. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

willingness to protect such animals; **Figure 4C**), but when considering the interaction with phylogeny, the willingness to protect decreased toward anthropomorphically looking animals that are phylogenetically less related to humans (e.g., insect with raised front legs; **Table 5**).

Size

Cuteness scores strongly depended on whether the animal is large or small and are biased in favor of small creatures (**Figure 5A**). In general, small animals that are phylogenetically closely related to humans were perceived as cuter than distant animals (**Figure 3B**), while small animals resembling humans with direct eye contact were rated cuter than large animals (**Table 3**). Women had a tendency to give higher cuteness ratings when considering small animals (**Figure 6A**).

As we expected, size modified the fear score as well. Small animals were rated as less menacing when compared to larger ones (**Figures 5B**, **6B**).

Our results showed that people were willing to protect small animals (**Figure 5C**) and that small quadrupedals were evaluated with slightly higher protection scores than small bipedals (**Figure 2B**).

Eye Contact

When considering animals with eye contact, they were evaluated as less cute in comparison with no eye contact (**Figure 7A**), even

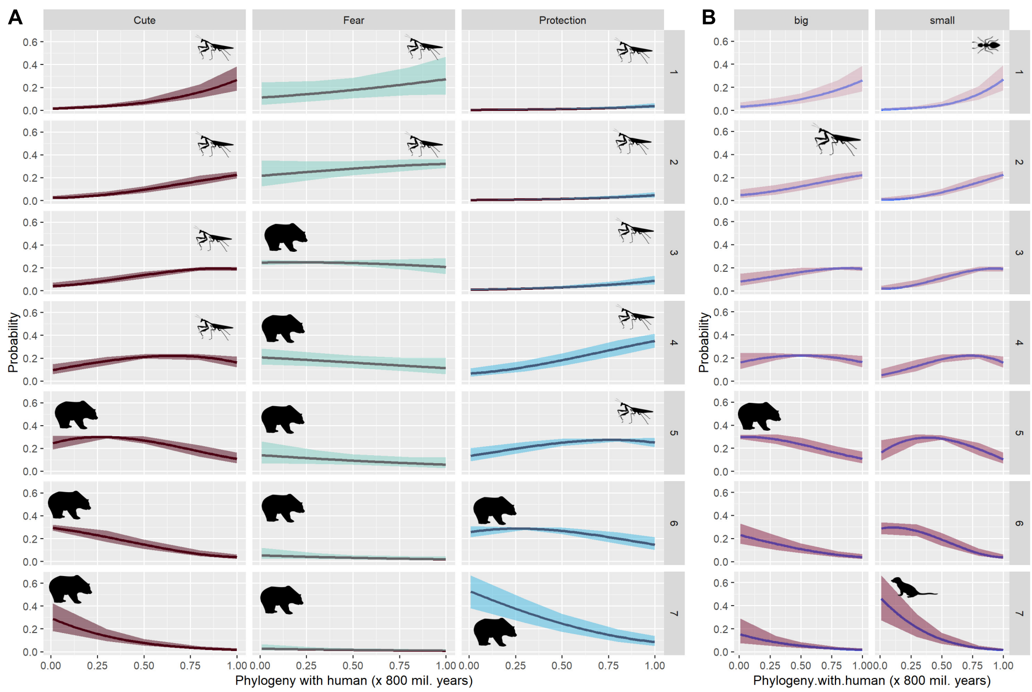

FIGURE 3 | Estimated probability of ratings for cuteness, fear and willingness to protection according to Phylogeny **(A)**, interaction effects of Phylogeny:Size for Cuteness **(B)**. Error areas indicate 95% confidence interval; numbers 1–7 refer to rating scores.

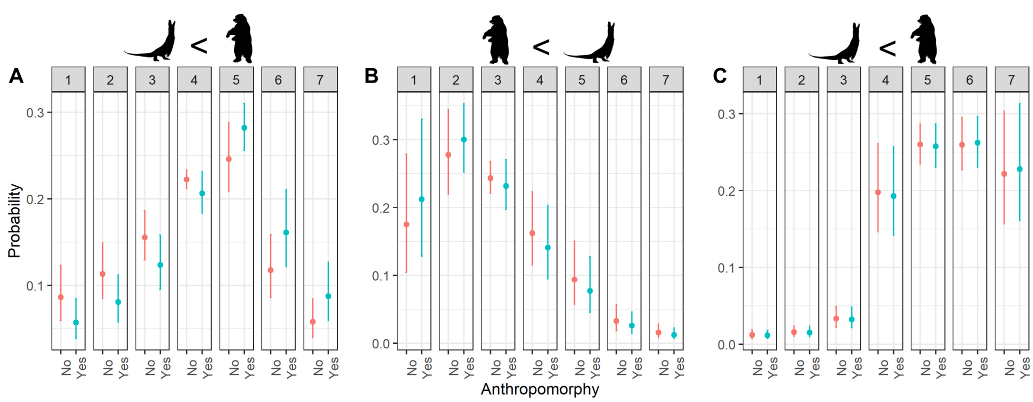

FIGURE 4 | Estimated probability of ratings for **(A)** cuteness, **(B)** fear, and **(C)** willingness to protection according to Anthropomorphy. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

though small anthropomorphic animals with eye contact were rated as cute (**Table 3**).

With regard to fear, eye contact increased the fear scores (**Figure 7B**), especially together with quadrupedalism (**Table 4**).

Eye contact was not statistically significant for willingness to protect as an individual factor nor for interactions (**Table 5**).

Gender

Even though gender was not statistically significant as an individual factor for the cuteness evaluation, the interactions with other factors were significant (**Table 3**). As we have mentioned, animals that are phylogenetically distant to humans (e.g., insects) were rated as less cute than phylogenetically close animals (e.g., mammals; **Figure 3A**), but the cuteness scores decreased more when they were evaluated by women (**Figure 8A**). Small animals were assigned higher cuteness scores when rated by women compared to the ratings of men (**Figure 6A**).

For fear evaluations, gender was statistically significant as an individual factor, and it also interacted with several other variables. Women had a tendency to give higher fear scores relative to men (**Figure 8B**). The most fearful evaluations were phylogenetically close animals rated by women, and the least fearful evaluations were phylogenetically distant animals rated by men (**Table 4**).

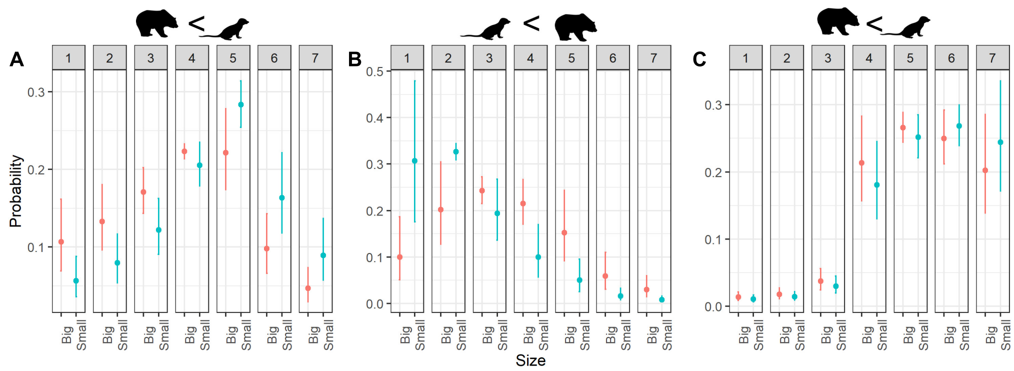

FIGURE 5 | Estimated probability of ratings for **(A)** cuteness, **(B)** fear and **(C)** willingness to protection according to Size. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

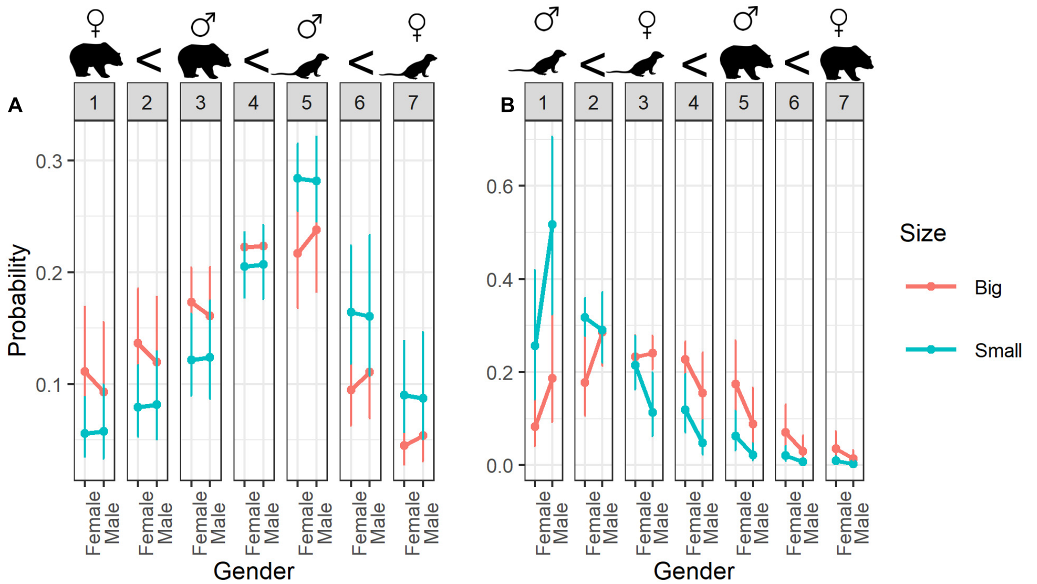

FIGURE 6 | Interaction effects of Gender:Size for **(A)** cuteness and **(B)** fear. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

Gender was not statistically significant for willingness to protection as an individual factor nor for interactions.

Relationship Between Cuteness, Fear, and Willingness to Protect Animals

Total cuteness scores positively correlated with willingness to protect animals and negatively correlated with perceived fear (Pearson r = 0.50 and −0.37, both $P < 0.001$, N = 349, respectively). Willingness to protect animals negatively correlated with perceived fear (Pearson r = −0.14, P = 0.01, N = 349).

DISCUSSION

As far as we are aware, this is the first study which systematically investigated whether the bipedal posture of animals influences their perception by humans. We found that bipedal posture significantly influenced all three investigated domains of animal perception: perceived cuteness, fear, and willingness to protect them. Moreover, these associations were influenced by the size of the animal, phylogenetical distance from humans, direct eye contact, and perceived anthropomorphism.

We hypothesized that animals with bipedal posture would be perceived as cuter than animals with quadrupedal posture. In line with this hypothesis originally proposed by Morris (1969), bipedalism enhanced the perceived cuteness under certain contexts—for example, the cuteness of small animals with bipedal posture was enhanced more than the cuteness of large species with bipedal posture. With regard to fear, large animals, particularly carnivores, elicited stronger fear judgments than small animals (Prokop et al., 2010; Staňková et al., 2021). In addition, large, but not small, animals with bipedal posture induced greater fear. These results can be explained from an evolutionary perspective, as large carnivores were common

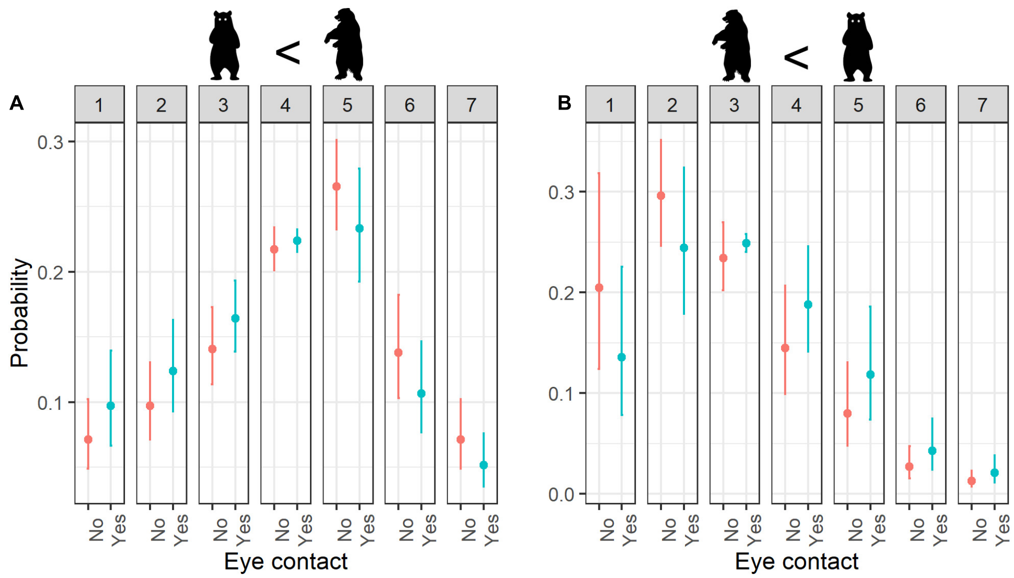

FIGURE 7 | Estimated probability of ratings for **(A)** cuteness and **(B)** fear according to Eye contact. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

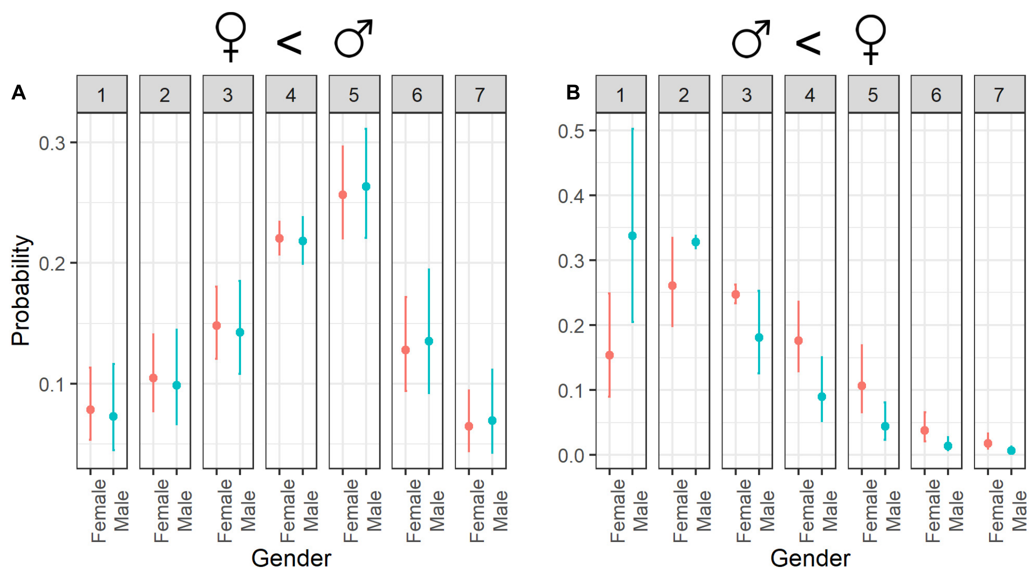

FIGURE 8 | Estimated probability of ratings for **(A)** cuteness and **(B)** fear according to Gender. Error bars indicate 95% confidence interval; numbers 1–7 refer to rating scores.

predators of our ancestors in Africa (Treves and Palmqvist, 2007). Women are more frequently victims of predatory attacks than men (Treves and Naughton-Treves, 1999), which can explain their greater fear of large-bodied animals. Moreover, predation pressure on humans continues, although on a smaller scale than in our evolutionary past (e.g., Treves and Naughton-Treves, 1999; Löe and Røskaft, 2004; Packer et al., 2005).

Phylogenetically distant animals were perceived as less cute than phylogenetically closer animals. This finding is consistent with the different methodological approaches previously documented (the capacity for an animal to feel pain: Plous, 1993; empathy toward animals: Miralles et al., 2019). The participants also indicated lesser willingness to protect phylogenetically distant species (e.g., invertebrates) than phylogenetically closer species (e.g., mammals), which suggests that our innate preference for cute animals (baby scheme, Borgi et al., 2014) and/or the ability to empathize with animals (Miralles et al., 2019) enhances our interest in the conservation of animals similar to us (Samples et al., 1986; Plous, 1993; DeKay and McClelland, 1996).

Although it is well known that people have negative attitudes toward invertebrates (e.g., Kellert, 1993; Schlegel and Rupf, 2010; Fukano and Soga, 2021), it is hard to establish powerful strategies regarding how these attitudes can be improved (Cardoso et al., 2011). We did not observe a positive trend toward willingness to protect invertebrates if they look more anthropomorphic (e.g., an ant with raised front legs). It seems that bipedal posture itself does not fully enhance anthropomorphism (Morris, 1969), though it makes a moderate contribution. We suggest that this result can be used in conservation campaigns, where certain unpopular invertebrates could be used as flagship species if they are photographed in a natural way. Fukano and Soga (2021), for instance, showed that when people saw photographs of insects with an indoor background, perceived disgust and danger for insects were higher compared to pictures with an outdoor background.

Contrary to our hypothesis, the participants were generally more willing to protect small quadrupedal animals compared with animals with bipedal posture. Small species could enhance perceived cuteness and, consequently, our interest in the conservation of these animals. However, human preferences and conservation efforts are directed toward rather large-bodied, charismatic mammals (Kontoleon and Swanson, 2002; Clucas et al., 2008; Sitas et al., 2009; Smith et al., 2012; Veríssimo et al., 2018). Albert et al. (2018) found that charismatic animals are beautiful/cute, dangerous/impressive, or rare/endangered. We used only two species (gorilla and bear) belonging to the list of charismatic animals of Albert et al. (2018). Thus, it seems that human willingness to protect is directed toward small, cute species over large-bodied but non-charismatic animals. It is still not clear, however, why bipedal posture did not contribute to willingness to protect animals. We speculate that the bipedal posture of certain large-bodied species could be perceived as too uncommon (e.g., capybara) and/or threatening, thus reducing perceived conservation needs. Perhaps the bipedal posture of small, cute species could enhance willingness to play rather than willingness to protect them. To support this idea, small animals in anthropomorphic posture with direct eye contact were rated as cute, and eye contact provides a foundation for communication and social interaction (Kleinke, 1986; Senju and Johnson, 2009).

LIMITATION

Since the perception of cuteness, fear, and willingness to protect an animal only according to a picture is a very complex process, we chose ratings (CLMM model) over simple pairwise comparisons. The main reason behind this methodological strategy is that the ratings for two items tell us not only which item is preferred but also the degree to which it is preferable, so ratings can be more informative than pairwise comparisons. Additionally, if we took into account the expected complex information from pairwise comparisons, we would need many more respondents. Heterogeneity and overparameterization of the model need to be solved in multifactorial dimensions.

CONCLUSION

Our research on how looking similar to humans influences the perception of animals showed that bipedal posture contributes to the perceived cuteness of (particularly small) animals. Cuteness is associated with willingness to protect animals, but bipedal posture itself did not enhance the conservation support for animals. It seems that the bipedal posture of large-bodied animals could be perceived as threatening or perhaps non-typical. Small bipedal animals, particularly those with direct eye contact, could initiate social interactions different from conservation needs. However, if phylogenetically distant and less cute animals look more anthropomorphic, they receive lesser intentions of willingness to protect. We did not experimentally manipulate perceived anthropomorphism; thus, more research in this field should be done before a definitive conclusion can be made.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: Data are available from authors upon request. Requests to access these datasets should be directed to corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PP, MZa, and PF designed the study. MZi analyzed the data. AP commented on the manuscript and improved the English. PP, MZa, and PF collected the data. All authors contributed equally in writing the manuscript.

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What Makes Spiders Frightening and Disgusting to People?

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The quality of human-animal interactions may crucially influence conservation efforts. Unfortunately, and despite their important roles in the functioning of the ecosystem, some animals are considered notoriously unpopular. Using the forced-choice paradigm, we investigated which cues humans perceive as frightening and disgusting in spiders, one of the most unpleasant animals in the world. The research was carried out with a representative sample of $N = 1,015$ Slovak adults. We found that perceived fear and disgust of spiders were triggered predominantly by enlarged chelicerae, enlarged abdomen, and the presence of body hair. Longer legs were associated with perceived fear as well; however, the presence of two eyes did not produce any statistical significance in terms of fear. We hope that further research in this field, where additional cues can be manipulated (e.g., color and number of legs), will improve conservation efforts by using an improved reputation of spiders in the eyes of the general public.

Keywords: attitudes toward animals, spiders, gender differences, human-animal relationship, morphology

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INTRODUCTION

Spiders are one of the most abundant and diverse orders of arthropods with nearly 50,000 known species (World Spider Catalog, 2021). As for other hyperdiverse groups, the conservation status of 99.5% of the species has not been assessed by the International Union for the Conservation of Nature (IUCN) (Seppälä et al., 2018; Milano et al., 2021). Data from few assessed species show, however, that habitat loss, urbanization, invasive species, pet trade, climate change, pollution, intense farming, and global insect abundance decline are major causes for the alarming loss of spiders species worldwide (Branco and Cardoso, 2020; Nyffeler and Bonte, 2020).

Although spiders play a key role in food webs ecosystem by regulating the density of other invertebrate herbivores and predators (Wise, 1995), their popularity with humans is low (e.g., Kellert, 1993; Davey, 1994a; Borgi and Cirulli, 2015; Prokop and Randler, 2018; Stanková et al., 2021). Furthermore, the prevalence of spider phobia (extreme innate fear of spiders) varies cross-culturally between 2.7 and 9.75% (Fredrikson et al., 1996; Oosterink et al., 2009; Zsido, 2017; Zsido et al., 2018; Polák et al., 2020a); it is considered as one of the most common animal phobias, particularly in women (Fredrikson et al., 1996). Spiders increase perceptual and attention processes in humans (Vuilleumier, 2005; Van Strien et al., 2009; New and German, 2015) from childhood (Prokop and Tunnicliffe, 2008; Rakison, 2009; LoBue, 2010). These processes do not seem to be generalized responses to small arthropods, since spiders are perceived as being more dangerous and disgusting than beetles, wasps, and butterflies (Gerdes et al., 2009).

Some researchers suggest that the fear of spiders can be explained in terms of biological preparedness (Seligman, 1971). More efficient search for threat-relevant objects, such as fears of spiders (Öhman et al., 2001; LoBue and DeLoache, 2008; LoBue, 2010), suggests that our ancestors responded quickly to dangerous animals, which ultimately enhanced their fitness (Penkunas and Coss, 2013; New and German, 2015); however, this explanation is problematic, because, unlike snakes, only a few species of spiders are dangerous to humans (Foelix, 1996). Some studies suggest that spiders are associated with attitudes of disgust and with survival strategies practiced in the Middle Ages. For instance, avoiding unclean, disgusting, and potentially contaminated places where spiders often occur (Davey, 1994b). Although some evidence suggests that Davey's hypothesis is incorrect, European descendants do not appear to be more afraid of spiders than people from areas that did not have a plague pandemic during the Middle Ages (Prokop et al., 2010a). Brain activity measured by using the early posterior negativity (EPN) turned out to be larger for snake pictures compared with spider pictures, which suggests that early attention to spiders is lower than attention to snakes (Van Strien et al., 2014a,b). Finally, fast detection and rapid learning in non-human primates are limited to snakes, but no similar evidence has been found for spiders (Kawai and Koda, 2016). These arguments seem to indicate that fear of spiders in human may have different roots than fear of snakes.

Because the evolutionary origin of fear of spiders in humans is still unclear, further research is needed to understand the main reasons as to why spiders are frightening and disgusting animals to most people (e.g., Polák et al., 2020a,b). In this study, we used a representative sample of Slovak people to examine which specific cues make spiders unpopular animals. We submit that this approach can contribute to an improvement in human-spider interactions. Conservation initiatives may improve their communication with the general public by avoiding cues, which were considered frightening or disgusting by people. Human emotions toward animals greatly influence their willingness to protect them (Prokop and Fančovičová, 2013a; Castillo-Huitrón et al., 2020); thus, research focused on public perception of undesired animals, such as spiders, is necessary. Perhaps, attention captured by spiders can be used for effective management in biodiversity conservation better than originally thought. Furthermore, identifying specific morphological cues of spiders that are frightening or disgusting may help us better understand the evolutionary origin of human fear/disgust of spiders. Previous research in this field was based on the analysis of responses of participants to open-ended questions (Cranshaw, 2006), or scaled items (Davey, 1991; Lindner et al., 2019). A review of the literature, in this field, reveals the absence of studies using experimental manipulation of cues in spider morphology to examine the effect of specific cues in the perception of this animal species as frightening or disgusting.

METHODS

Participants and Procedure

This study was implemented online during the spring semester of 2021. Participants in the study consisted of $N = 1,015$ Slovak citizens with ages ranging between 18 and 69 years; they were recruited by the authors *via* online networks (Google Forms, Facebook) and through private e-mails; the research study was also advertised on the university web page. In all cases, and prior to assent to participate, each individual was informed that the focus of the research study was on the traits that humans find disgusting and dangerous in spiders. They were also informed that their participation, which entailed the completion of a short survey, was unpaid and voluntary. Previous experiences of authors suggest that time-spending questionnaires greatly discourage people to fill online questionnaires; thus, the most important questions were only included to obtain a representative sample sizes. The participants were presented with 15 pairs of spider images that had some body traits manipulated (only one image was modified to create the 15 pictures); they were asked to choose one image from each pair that in their views was perceived as disgusting. The same images were presented randomly a second time, the task was to choose images that were perceived as frightening. We used these two emotions because both are designed to protect an individual differently: disgust protects against pathogen contamination (e.g., Curtis et al., 2004), while fear prepares the body for fight-or-fly response (Gray, 1987). Furthermore, spiders elicit both disgust and fear (e.g., Gerdes et al., 2009; Polák et al., 2020b) and these emotions are important in the willingness to protect animals (Prokop et al., 2013; Castillo-Huitrón et al., 2020). The original picture met the following criteria: it conveyed the general spider pattern and included traits that could be easily manipulated to produce a poll of pictures instead of presenting participants with particular species of spiders.

Stimuli

According to the relevant literature (Davey, 1991; Cranshaw, 2006; Lindner et al., 2019), we modified several parts of the spider body, legs, eyes, hair, chelicerae, and abdomen (**Table 1**, **Figures 1–6**).

The original image (4620 × 2968 px | 39.1 cm × 25.1 cm | 300 dpi | JPG) has been purchased from "123RF.com" and processed in the Photoshop software (CS5 Version 12.0). The final images were obtained by manipulating body parts in the original image, the altered images were intended to emphasize the desired body

TABLE 1 | Aesthetic characteristics manipulated for five spider "types."

Variable	Levels	Prediction
Legs	Original Big	Large leg = increased legginess (Davey, 1991; Cranshaw, 2006; Lindner et al., 2019)
Hair	No Yes	Hairiness = important movement cue eliciting fear (Davey, 1991; Cranshaw, 2006; Lindner et al., 2019)
Eyes	Original Big	Big black eyes = fear (Cranshaw, 2006)
Chelicerae	Original Big	Large chelicerae = danger of being bitten (Cranshaw, 2006)
Abdomen	Original Big	Large abdomen = large size appearance (Davey, 1991; Cranshaw, 2006; Lindner et al., 2019)

FIGURE 1 | Experimentally manipulated eyes of spider.

FIGURE 2 | Experimentally manipulated body hair of spider.

FIGURE 3 | Experimentally manipulated chelicerae of spider.

FIGURE 4 | Experimentally manipulated legs of spider.

characteristic (legs, eyes, chelicerae, abdomen, and hairs). The poll of spider pictures includes one original and five modified images, which were paired in 15 possible dyads.

FIGURE 5 | Experimentally manipulated abdomen of spider.

FIGURE 6 | Original spider image.

Statistical Analyses

Analyses were conducted in R 4.0.4 (R Core Team, 2021). Discrete choice experiment (DCE) model estimates were used to predict the scariest and the most disgusting traits in a spider body. We used the DCE with unlabeled alternatives, a 15 choice set with two alternatives each, and described with five attributes. The DCE model was analyzed using conditional logit models in the R package "survival" (Therneau, 2021). The aesthetic characteristics (attributes) in **Table 1** were used as predictor variables in multiple regression model. We added individual-specific variables (characteristics of decision-makers, gender, and academic background in biology/biology education). Since the alternatives are unlabeled, we used the interaction between alternative and individual-specific variables. All aesthetic characteristics were entered in the final logit models, but only statistically significant interactions were included. Hazard ratio (HR) is the ratio of chance of a picture with a modified particular trait to be chosen in place of an original image (or image without modified traits). When considering the particular trait, if $HR < 1$ the probability for a picture with a modified trait to be chosen is lower than for the original picture and vice versa.

RESULTS

Overall, 1,015 respondents with ages 18–69 years (794 females, 221 males) were included in the dataset. The demographical characteristics of the respondents are shown in **Table 2**.

Fear

When considering the answers from all participants, the scariest traits of a spider body were abdomen followed by chelicerae (**Tables 3**, **4**). Indeed, spiders with enlarged abdomen or chelicerae were selected more often than the original image. In comparison with abdomen and chelicerae, hairiness was rated with lower fear scores. When comparing the responses of male and female participants, there was a difference in the perception of chelicerae. While for female respondents, the probability of choosing siders with large chelicerae was 2.97 (compared to the image without enlarged chelicerae), for male participants, the probability was 2.05. As stated before, respondents were also more likely to identify images with hairy spiders as scary than those without hair; however, female participants were more afraid of hairy spiders than males (the probability to be chosen is 2.11 in females and 1.49 in males). Enlarged eyes and legs were not statistically significant when evaluating fear. When looking at the responses from participants with a background in biology, the results indicate that these participants consider spiders with enlarged chelicerae to be more frightening as compared with those without training in biology. The reliability of the spider body characteristics according to the fear is shown in **Figure 7**.

Disgust

In the exploration of the disgust factor against spider body traits, we found out that in general, the abdomen characteristic was rated as the most disgusting trait (**Tables 4**, **5**). Spiders with enlarged chelicerae, hairy body, and spiders with enlarged legs were also considered disgusting in this order. The enlarged eye

TABLE 2 | Demographic characteristics of participants (bio edu, education in biology).

Demographic characteristics		Number of participants
Sex	Female	794
	Male	221
Age	18–29	893
	30–39	69
	40–49	32
	50–59	16
	60–69	5
Bio Edu	Yes	547
	No	468
Education	University	404
	High school	607
	Basic	4

TABLE 3 | A specific number of selections for each pair for each image in fear perception testing (general, gender, and biological education).

Number of image pair	Changed attribute					
	Eyes	Hairy	Chelicerae	Legs	Abdomen	Control
1	440	575				
2		384	631			
3					871	144
4		336			679	
5			878			137
6	503			512		
7			468		547	
8	173		842			
9				379		636
10	198				817	
11			687	328		
12		622				393
13				299	716	
14	528					487
15		567		448		
Selections General	1,842 (36.3%)	2,484 (48.9%)	3,506 (69.1%)	1,966 (38.7%)	3,630 (71.5%)	1,797 (35.4%)
Selections of females	1,431 (36%)	1,973 (49.7%)	2,804 (70.6%)	1,517 (38.2%)	2,807 (70.7%)	1,378 (34.7%)
Selections of males	411 (37.2%)	511 (46.2%)	702 (63.5%)	449 (40.6%)	823 (74.5%)	419 (37.9%)
Selections of biologists	991 (36.2%)	1,268 (46.4%)	1,928 (70.5%)	1,113 (40.7%)	1,945 (71.1%)	960 (35.1%)
Selections of non-biologists	851 (36.4%)	1,216 (52%)	1,578 (67.4%)	853 (36.5%)	1,685 (72%)	837 (35.8%)

TABLE 4 | Model estimates for multiple regressions of the mean degree of fear and disgust, where positive estimates suggest a variable increase in fear/disgust.

Variable	Disgust		Fear	
	Hazard ratio (95% CI)	Z statistic and *p*-value	Hazard ratio (95% CI)	Z statistic and *p*-value
Intercept	1.03 (0.95–1.11)	$z = 0.68$ $p = 0.497$	1.05 (0.98–1.13)	$z = 1.39$ $p = 0.165$
Legs (Big)	**1.11 (1.02–1.22)**	**$z = 2.41$ $p = 0.016$**	0.99 (0.91–1.09)	$z = -0.17$ $p = 0.869$
Abdomen (Big)	**3.81 (3.51–4.14)**	**$z = 31.71$ $p < 0.001$**	**2.96 (2.73–3.21)**	**$z = 26.36$ $p < 0.001$**
Chelicerae (Big)	**2.46 (2.09–2.89)**	**$z = 10.88$ $p < 0.001$**	**2.05 (1.75–2.41)**	**$z = 8.77$ $p < 0.001$**
Eyes (Big)	0.99 (0.86–1.14)	$z = -0.11$ $p = 0.91$	0.88 (0.77–1.02)	$z = -1.72$ $p = 0.086$
Hairy (Yes)	**1.47 (1.24–1.75)**	**$z = 4.45$ $p < 0.001$**	**1.49 (1.26–1.76)**	**$z = 4.58$ $p < 0.001$**
Chelicerae (Big): Gender (Female)	**1.47 (1.26–1.7)**	**$z = 4.99$ $p < 0.001$**	**1.45 (1.25–1.68)**	**$z = 4.89$ $p < 0.001$**
Chelicerae (Big): Bio Edu (Yes)	1.05 (0.92–1.19)	$z = 0.74$ $p = 0.46$	**1.26 (1.11–1.44)**	**$z = 3.62$ $p < 0.001$**
Hairy (Yes): Gender (Female)	**1.32 (1.15–1.53)**	**$z = 3.81$ $p < 0.001$**	**1.42 (1.23–1.64)**	**$z = 4.8$ $p < 0.001$**
Hairy (Yes): Bio Edu (Yes)	**0.77 (0.68–0.86)**	**$z = -4.33$ $p < 0.001$**	0.89 (0.79–1)	$z = -1.91$ $p = 0.056$
	Concordance = 0.64 (±SE 0.01) Adjusted rho2 = 0.105		Concordance = 0.65 (±SE 0.01) Adjusted rho2 = 0.116	

Variables where $p < 0.05$ are shown in bold. Only statistically significant interactions are included.
CI, confidence interval.

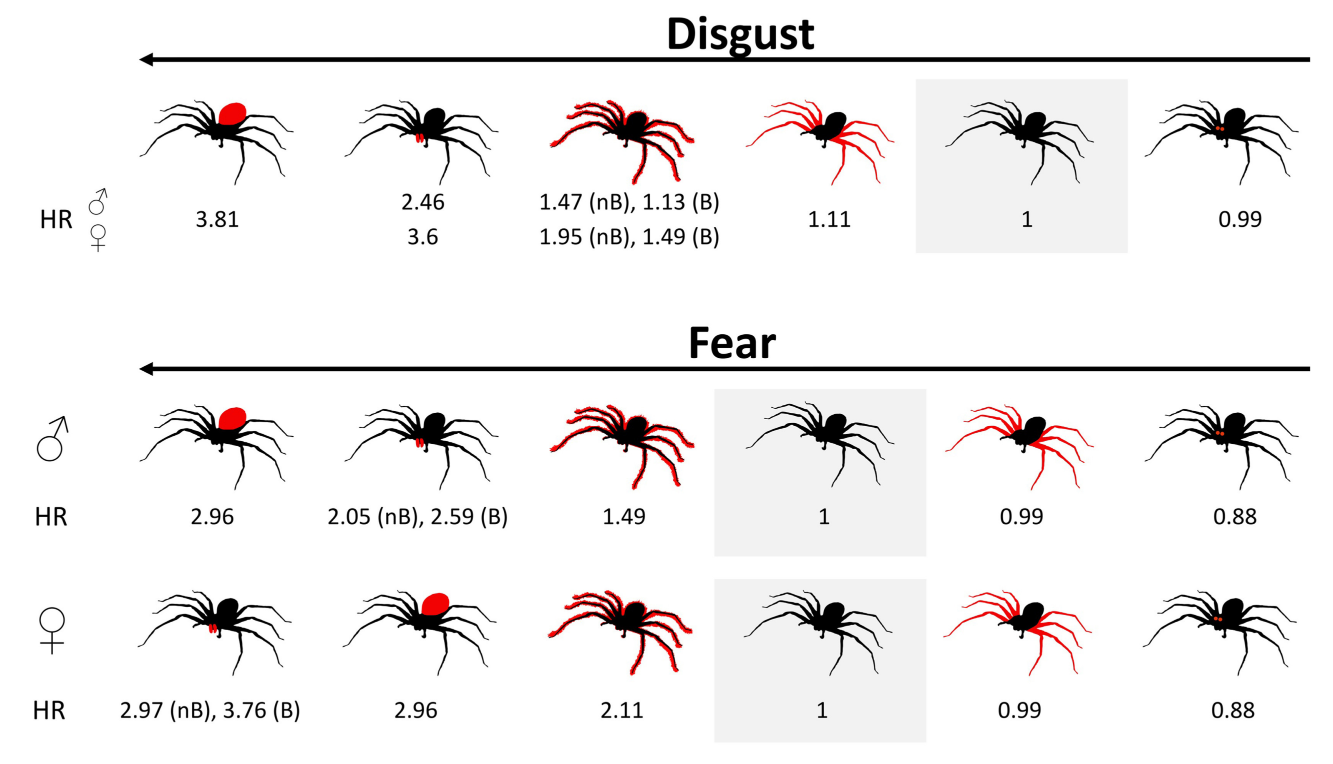

FIGURE 7 | Reliability of spider body traits for disgust and fear perception. HR, hazard ratio; B, biologists; nB, non-biologists; gray square, control.

TABLE 5 | Number of choices for each pair for each image in disgust perception testing (general, gender, and biological education).

Number of image pair	Changed attribute					
	Eyes	Hairy	Chelicerae	Legs	Abdomen	Control
1	440	575				
2		384	631			
3					871	144
4		336			679	
5			878			137
6	503			512		
7			468		547	
8	173		842			
9				379		636
10	198				817	
11			687	328		
12		622				393
13				299	716	
14	528					487
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Choices of non-biologists	851 (36.4%)	1,216 (52%)	1,578 (67.4%)	853 (36.5%)	1,685 (72%)	837 (35.8%)

trait was not statistically significant for the disgust factor. When considering the gender of the participants, the perception of chelicerae as the second most disgusting trait was different. While female respondents chose enlarged chelicerae 3.6 times more often, the probability that males would choose the same trait was only 2.46. Hairy spiders were also considered to be more disgusting by the female (probability to be chosen is 1.95) than by male participants (probability decreased to 1.47). Interestingly, hairy spiders tended to be rated as less disgusting by respondents identified as biologists than by non-biologists. A diagram of the reliability of spider body traits for disgust perception is shown in **Figure 1**.

DISCUSSION

Cues triggering fear/disgust of spiders have long been a topic of interest to researchers in this field. Previous research has shown that "legginess," spider movement, spider size, and hairiness (Davey, 1991; Lindner et al., 2019) or perceived danger (Cranshaw, 2006) are prominent cues associated with fear and disgust of spiders. In this article, we used a forced-choice paradigm and a representative non-clinical sample of participants to examine which of the visual stimuli elicits these two emotions. Although we did not investigate the effect of factors in the positive aesthetic domain, we studied the influence of negative values (Ceríaco, 2012) to determine what spider cues should be avoided in the conservation programs.

Chelicerae and abdomen were the scariest body traits in spider. Female participants perceived enlarged chelicerae as more frightening than their male counterparts. In contrast, and for both groups, the abdomen of the spider elicited more disgust, while enlarged chelicerae, hairiness, and enlarged legs also contributed to the perception of spiders as disgusting animals. Female respondents considered hairiness more disgusting than males.

Often, animal weapons that can potentially threaten humans come in the form of straight objects; thus, it is not surprising to find out that humans have an evolutionary predisposition to pay attention to potentially harmful objects, such as sharp teeth, claws, animal spikes, and horns (Wrangham and Peterson, 1996; Souchet and Aubret, 2016). This finding is in agreement with Cranshaw's (2006) study reporting on the views of students of bites and perceived danger as underlying factors related to fear of spiders. Interestingly, however, participants rarely cited chelicerae as an indication of fear in some of the previous studies (Davey, 1991; Lindner et al., 2019). This finding suggests that visual cues need to be considered in research on emotions elicited by spiders; a reason for this assumption is that certain subtle morphological characteristics could alter visual perception, but could be overlooked when responses are recorded solely by scaled items.

Enlarged abdomen significantly contributed to the rating of fear and disgust; however, this trait seemed to play a more prominent role in the perception of disgust than fear. We suggest that the abdomen of spider plays a dual role in perceived fear and disgust. An enlarged abdomen may visually enlarge the body of the spider, and the larger the size of an animal, the more likely it is perceived as a threat for humans (Prokop et al., 2010b; Stanková et al., 2021). This may be a simple mechanism as an enlarged abdomen can increase perceived fear. Enlarged abdomen, however, may also superficially resemble a big tick or other blood-eating ectoparasites that can transmit serious infections to humans (e.g., de la Fuente et al., 2008).

The presence of body hair seems to be significantly associated with both fear and disgust of spiders (Davey, 1991). We suggest that the rationale for this perception (fear of hairiness) is that body hair (or fur) when standing up in many mammals occur when the animal is threatened. The elevated body hair strategy makes the animal appear bigger than its original size (Bubenik and Bubenik, 1990). Body hair can be therefore perceived as a cue of fear. With respect to the emotion of disgust, body hair correlates with disgust sensitivity (Tiggemann and Lewis, 2004), perhaps because hairy bodies can suffer from high loads of ectoparasites that end up transferring diseases to the host animal, and ultimately decreasing the fitness of an individual (Rantala, 1999; Prokop et al., 2013). Thus, it is not surprising to find that their presence was also associated with disgust of spiders.

In general, women are more feared of spiders than men (e.g., Cornelius and Averill, 1983; Gerdes et al., 2009), and it is possible that certain gender differences, in this study, could be the result of greater fear among female participants. In particular, spider chelicerae were significantly more associated with the fear of spiders in females than in the male group. Furthermore, hairiness was also more associated with disgust by females than by male respondents. Regarding the former, female participants reported greater fear of predators than male participants (e.g., Røskaft et al., 2003; Prokop and Fančovičová, 2010, 2013b). Perhaps, female lower physical condition (Puts, 2010) and greater vulnerability to predation (Treves and Naughton-Treves, 1999) could be ultimately responsible for a greater fear of sharp spider chelicerae. Regarding the latter, females are more disgust sensitive than males (Curtis et al., 2004), and, therefore, hairy spiders were perceived as more disgusting for females than for males.

The long legs feature is thought to promote fear of spiders (Davey, 1991; Lindner et al., 2019), and results in this study partly support this idea; however, this trait is not a prominent factor in eliciting fear and disgust. We suggest that legginess should be investigated with manipulation of the total number of legs of spiders and with interactive videos, where spider movement can be observed along with modified legs in relation to their size or number before reaching any conclusion. Contrary to these findings, spider eyes did not show any significant influence on ratings of fear or disgust. We suggest that this null effect could be caused by insufficient manipulation (e.g., eyes could be bigger) or by the fact that eye contact in humans triggers altruism rather than aversive response (e.g., Bateson et al., 2006).

In this study, participants with a background in biology were less fearful of snakes and spiders than those without training in this discipline (Polák et al., 2016, 2020a). Compared with the non-biologists group, we found that biologist participants rated hairy spiders less frightening and less disgusting (although marginally not significant). Biologists are expected to be knowledgeable about animals, and their general interest in animals should be higher than in non-biologists.

The conservation of spiders seems to be more difficult than that of any other invertebrates (and most vertebrates), and this is partly due to the fact that at least in the Western culture, spiders are considered dangerous, small, and apparently insignificant (Branco and Cardoso, 2020). In addition, the absence of any economic benefits from investing in their protection makes spider conservation even more difficult. Understanding beliefs and preferences among the public may result in more successful pro-environmental actions (Alves et al., 2012). Compared with research on vertebrates, it seems that conservationists should avoid some universal features on animal bodies, such as large bodies, short legs, small eyes, and dull coloration (Frynta et al., 2019; Rádlová et al., 2019). In addition to these features, we found that long legs and excessive hairy bodies should be avoided when presenting a representative spider specimens to the public. Regarding body coloration, further research on spiders is required.

Citizen science and educational programs not only would increase awareness of animal species that can be easily identified species (Devictor et al., 2010) but also a powerful tool to address the negative perception of spiders (Wagler, 2017; Albo et al., 2019). We acknowledge that individuals by themselves are not in the best position to establish protected areas and manage the conservation of endangered species, however, we believe that everyone can avoid killing spiders in their households, and instead relocate them to different areas. Similarly, everyone could reduce the use of pesticides which are harmful not only for spiders but also for insects, a major food source of almost all known spider species. Finally, almost everyone can reduce mowing their lawns to support the biodiversity of insects and consequently spiders. We believe that more comprehensive investigations on the effect of cues as predictors of dangerous/disgusting perceptions can help in developing empathy for spiders. We consider this study as an initial step in this direction. Although we still do not know which cues are attractive, we have provided some evidence that unattractive (i.e., dangerous/disgusting) cues need to be considered and avoided in spider conservation programs.

CONCLUSION

Large chelicerae, abdomen, and hairy bodies are specific cues that promote fear and disgust of spiders. Each emotion is associated with slightly different cues, and female participants appear to be more sensitive to sharp, fear eliciting cues, such as chelicerae, as well as to disgust-eliciting cues, such as body hair, than their male counterparts. We consider that with this study, we have taken a further step toward understanding the bad reputation people assign to spiders. It seems that the use of manipulated visual cues produces different results than scores obtained by rated items. Visual cues, therefore, need to be considered in similar research in the future. We also submit that further research needs to consider additional visual cues that we did not manipulate (e.g., color), as well as videos, where spider movement and leg length and number will be experimentally treated. Finally, it would be helpful to determine whether individuals who are fearful of spiders perceive certain body parts as more frightening or disgusting than those in non-clinical samples. We hypothesize that careful identification of these cues can help improve conservation strategies by using more positive human-spider interactions.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because this study does not require ethical approval. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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A Framework of Observer-Based Biases in Citizen Science Biodiversity Monitoring: Semi-Structuring Unstructured Biodiversity Monitoring Protocols

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Citizen science, whereby ordinary citizens participate in scientific endeavors, is widely used for biodiversity monitoring, most commonly by relying on unstructured monitoring approaches. Notwithstanding the potential of unstructured citizen science to engage the public and collect large amounts of biodiversity data, observers' considerations regarding what, where and when to monitor result in biases in the aggregate database, thus impeding the ability to draw conclusions about trends in species' spatio-temporal distribution. Hence, the goal of this study is to enhance our understanding of observer-based biases in citizen science for biodiversity monitoring. Toward this goals we: (a) develop a conceptual framework of observers' decision-making process along the steps of monitor – > record and share, identifying the considerations that take place at each step, specifically highlighting the factors that influence the decisions of whether to record an observation (b) propose an approach for operationalizing the framework using a targeted and focused questionnaire, which gauges observers' preferences and behavior throughout the decision-making steps, and (c) illustrate the questionnaire's ability to capture the factors driving observer-based biases by employing data from a local project on the iNaturalist platform. Our discussion highlights the paper's theoretical contributions and proposes ways in which our approach for semi-structuring unstructured citizen science data could be used to mitigate observer-based biases, potentially making the collected biodiversity data usable for scientific and regulatory purposes.

Keywords: citizen science, biodiversity, monitoring, biases, framework

INTRODUCTION

The world's ecosystems are undergoing rapid and significant changes, characterized by a continuous decline in the abundance of insects, birds and mammals. From a centennial perspective, these changes are clearly evident (Attenborough, 2020). To take action in time and help in species conservation, scientists must be able to detect changes and identify warning signs much quicker (Robinson et al., 2021). However, several factors limit the ability of traditional methods to detect these changes. Traditional scientific monitoring methods rely on systematic protocols and professionally trained observers, and are thus costly and difficult to scale (Robinson et al., 2021). As a consequence, long-term and wide-scale monitoring initiatives are often limited to very few sampling sites within limited regions and to particular times, deeming the attempt to generalize to different places and times problematic. Furthermore, given the budget constraints and scientists' focus on particular species, most of a region's species are not monitored systematically, limiting ecologists ability to consider inter-species interactions and thus making it difficult to assess long-term trends in the ecological system.

Citizen science (CS), based on public participation in scientific research (Vohland et al., 2021), presents an alternative to traditional systematic protocols in ecological monitoring (Conrad and Hilchey, 2011; Haklay, 2013; Bonney et al., 2014; Crain et al., 2014; Wiggins and Crowston, 2015). Citizen science has been applied to multiple conservation purposes, such as estimating species dynamics, mapping species distributions and studying climate change ecology (Dickinson et al., 2010; Powney and Isaac, 2015; Callaghan et al., 2020). More broadly, citizen science is becoming a powerful means for addressing complex scientific challenges (Cooper et al., 2014; Ries and Oberhauser, 2015). The scope of CS projects for ecological monitoring has increased immensely in recent years, providing an important means for data collection, and is playing a pivotal role in conservation, management and restoration of natural environments (Bonney et al., 2009; Dickinson et al., 2010; Skarlatidou and Haklay, 2021). It is estimated that the number of CS projects increases annually by 10% (Pocock et al., 2017).

Citizen science projects can be loosely categorized along a structured-unstructured continuum (Welvaert and Caley, 2016; Kelling et al., 2019). Participants of structured projects must adhere to a formal sampling protocol, which defines all the aspects of the sampling events, including location, duration, timing, target species, etc. In contrast, unstructured, non-systematic, CS projects facilitate reporting that do not impose any guidance, and participants are free to report any species they observe without any spatio-temporal restrictions (i.e., monitoring is opportunistic). As the degree of lack of structure of a project increases, the ability to deduce statistically sound inferences substantially decreases (Kelling et al., 2019). Structured CS projects provide more verifiable data, suitable for scientific analyses, but as a trade-off might suffer from a lack of participants or funding due to the complexity of policies. In contrast, unstructured monitoring, which characterize many of CS biodiversity monitoring projects (Pocock et al., 2017), is preferable for the wide audience due to data collection flexibility, but is more susceptible to observer-based biases (Tulloch and Szabo, 2012; Isaac and Pocock, 2015; Boakes et al., 2016; Callaghan et al., 2019; Kirchhoff et al., 2021). These biases may be broadly classified into three categories: temporal, spatial and species-related biases (Isaac and Pocock, 2015). For example, observers' reports may be spatially clustered due to ease of access to some areas, such as those close to the observer's residence or commute route (Leitão et al., 2011; Geldmann et al., 2016; Neyens et al., 2019), and the difficulty in accessing other areas (Lawler et al., 2003; Tulloch and Szabo, 2012). Such reporting patterns yield spatial redundancies or gaps in the collected data (Callaghan et al., 2019). Similarly, observers' temporal activity patterns and their tendency to report some species more than others may introduce additional biases.

Semi-structured projects represent a middle point between structured and unstructured protocols, allowing participants much autonomy in selecting what, where and when to monitor, but require that details of the monitoring process be reported in order to account for variation and bias in the data-collection process (Kelling et al., 2019). Such semi-structured approaches have proved highly effective in some areas. Namely, building on the long history of citizen's involvement in birdwatching, initiatives like eBird[1] (Sullivan et al., 2009, 2014) are playing an important role in tracking trends in bird population, much owing to the valuable work by the Cornell Lab of Ornithology. Still, for species other than birds, semi-structured CS projects have had a limited scientific impact. Conversely, unstructured CS projects, such as iNaturalist[2], with their wide coverage of taxa, present an alternative. However, due to their inherent biases, there are relatively few scientific reports of species abundance that are based on unstructured presence-only CS data.

The untapped potential of unstructured CS provides the impetus for our research, and the objective for our research program is to develop tools and methods for accounting for biases, so as to utilize unstructured CS data to meet scientific objectives. Toward this wide-ranging objective, the goal of this paper is to provide a framework for understanding biases associated with the reporting process of unstructured citizen projects, with the expectation that our approach would be utilized to quantify biases and account for them in statistical ecological models. We propose a method for semi-structuring unstructured citizen science data by collecting additional data from observers using a questionnaire.

Prior studies proposed conceptualizations of citizen science projects, by offering a variety of typologies, for example distinguishing between unstructured, semi-structured and structured monitoring protocols (Welvaert and Caley, 2016; Kelling et al., 2019), whether reporting is intentional or not (Welvaert and Caley, 2016), and classifying projects based on their organization and governance (e.g., the degree of citizen involvement is the scientific project) (Cooper et al., 2007; Wiggins and Crowston, 2011; Shirk et al., 2012; Haklay, 2013). Here we propose an alternative to the typological perspective, offering a process-based framework that considers an individual observer's decision-making steps. We study individual observers' considerations, which in aggregate yield biases in the communal database of observations. To the best of our knowledge, this is the first study to introduce such a process-oriented framework for studying observer-based biases.

[1]https://ebird.org/, with over 700 million observations as of March 2021.

[2]https://www.inaturalist.org/, with close to 60 million observations as of March 2021.

We draw a distinction between biodiversity monitoring citizen science projects that base their quality assurance and provenance procedures on observers' expertise and reputation ("expertise-based") as opposed to projects that require evidence and are based on a communal deliberation process ("evidence-based") (Guillera-Arroita et al., 2015). As we show later, this distinction has important implications for observers' decision-making process, as well as to the biases that are introduced during this process.

The paper continues as follows: in the next section we introduce our decision-based conceptualizations of the observation process in unstructured citizen science; we then proceed to offer an approach for semi-structuring unstructured citizen science data; we follow with an empirical illustration of our approach using data from iNaturalist; finally, we conclude with a discussion of the study's contributions, highlighting the paper's practical implications and discussing ways in which the study could be extended in future research.

THE PROPOSED FRAMEWORK

Our proposed framework for understanding observer-based biases is grounded in the reporting process that an observer goes through (Kéry and Schmid, 2004; Kelling et al., 2015, 2019). The framework was developed through a synthesis of the literature on the existing practices in citizen science, and then validated and refined through feedback received from practitioners. Our framework takes a decision-making approach, treating an observer's monitoring activity as a series of decisions. These decisions may be influenced by both species-related features (e.g., species abundance in the region, the features that determine how easy it is to detect a species) and observer-related factors, such as their expertise, preferences, and monitoring equipment. Our framework is focused on the latter—observer-related biases—accounting for observer's considerations regarding: selecting the spatial, temporal and taxonomic target for *monitoring*, *detecting* and *identifying* the species, and *recording and sharing* the observation. **Figure 1** below illustrates our proposed framework.

We note that this 3-phase decision-making process does not apply equally to all types of citizen science projects. For example, expertise-based projects, such as eBird, emphasize the ability to taxonomically identify the detected bird (Bonney et al., 2009; Sullivan et al., 2014). In contrast, evidence-based projects, such as iNaturalist, do not require that species are identified by the observer, as they could be identified later by other community members, based on the photo (Wiggins and He, 2016). Evidence-based projects highlight the considerations that determine the recording and sharing of species (e.g., personal preferences). Thus, the salience of each decision-making step in our proposed framework may differ between citizen science projects. During the reporting process, first an observer commonly makes a decision regarding the species or taxon one is interested in recording, the place and time where the observer would monitor (Welvaert and Caley, 2016). Once decisions regarding *monitoring* were made, observers' ability to *detect and identify* species is influenced by the observer's expertise and the technical equipment's affordances, such as the camera's zooming capabilities. While prior studies have treated detection and identification as distinct processes (Kelling et al., 2015), we opted to combine the two in a single step, because not all unstructured projects require that the species be identified prior to recording the observation. Moreover, similar factors affect observers' considerations pertaining to detection and identification (more below). Finally, once detected and identified, observers' inclinations (e.g., preference for a species) and practicalities will determine the decision of whether to *record and share* the observation. Most often, when using current reporting methods (i.e., smartphone app), the observation is automatically shared within a common database as it is recorded. However, in some cases, such as when recording the observation with a professional camera, the observation is recorded only at a later time. The equipment used and the method for sharing the observation have a significant impact on the observation's reliability (Wiggins and He, 2016). We introduce the notion of "recordability" to refer to the likelihood of *recording and sharing* the observation, once the species has been detected and identified.

Putting aside species-related factors (e.g., species abundance that are outside the scope of the current analysis), observers' considerations will influence: (a) the likelihood of *monitoring* a particular species in a certain place and time; (b) the likelihood of *detecting and identifying* the species, conditional on the probability of monitoring; and (c) the likelihood of *recording and sharing* the observation, conditional on the detected and identified species (i.e., *recordability*) (**Figure 1**).

Each of the three steps in our framework is influenced by considerations related to species, the geography of the region (e.g., vegetation, weather) and time (season, time of day) (August et al., 2020). The decision to *monitor* is shaped by the target species (or alternately, a non-targeted observation outing), the area to be monitored, and the time (season, day a week, and time of day) when the observer choses to go out for a monitoring excursion (Callaghan et al., 2019; Neyens et al., 2019). *Detection and identification* are influenced by the observers' attention to a particular species, their expertise (Yu et al., 2010; Johnston et al., 2019) and the photography equipment used (e.g., the use of zoom-enabled cameras), as well as by the conditions at the place and time of observations and the factors determining visibility, such as weather conditions. For example, an expert observer is able to both detect species more easily (e.g., by relying on auditory cues) and more accurately identify them (August et al., 2020). Likewise, an equipment that enhances eyesight (e.g., zoom-enabled camera) may facilitate both easier detection and a more accurate identification (Wiggins and He, 2016). Finally, we suggest that the decision whether to *record and share* the observation and upload it to the online archive is determined by three factors: (a) the observer's perceptions, for example believing it is more important to report certain species; (b) technical constraints, for example the difficulty of uploading photos that were taken using a professional camera; and (c) spatial and temporal factors, such as limited internet connection at certain areas and times. **Table 1** below provides examples of how species-related, spatial and temporal factors affect observers' considerations.

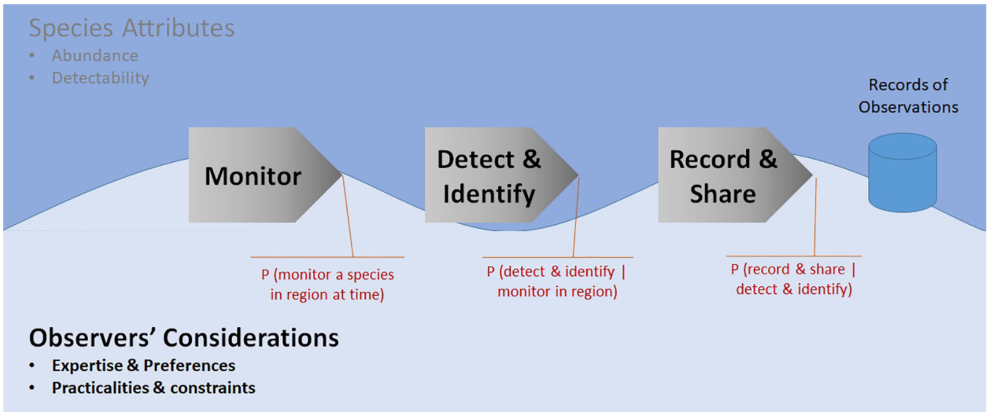

FIGURE 1 | Our proposed framework: an observer's participation process as a series of consideration regarding: monitoring, detecting and identifying, and recording and sharing. Assuming known species, spatial and temporal attributes, the results of each consideration is a relevant probability.

TABLE 1 | Examples of how species-related, spatial and temporal considerations affect observers' decisions in the three phases of the monitoring process.

Considerations related to:	**Observation process**		
	Monitor	**Detect and identify**	**Record and share**
Species	Attempt to observe wolves and plan trip to place/time where wolves are regular	Use professional camera with powerful zoom-in capabilities, allowing to more accurately identify the species. Be an expert on insects, and thus have the ability to identify insects with greater confidence	Love gazelles and thus record every gazelle encountered (choosing not to record detected jackals)
Space	Opt to record close to one's residence or at an ecological hotspot	Travel to an area with high vegetation, which hinders species' detection and identification	Travel to an area with limited internet connection
Time	Prefer to record during winter and at mid-day	Go on excursions only during daytime, missing nocturnal species	Detecting and identifying a wolf after a long workday, saving the effort of recording

OPERATIONALIZING OUR FRAMEWORK: SEMI-STRUCTURING UNSTRUCTURED MONITORING PROTOCOLS

In this section we offer an approach for semi-structuring opportunistic citizen science protocols by collecting a limited set of basic information about how participants make their observations. Namely, we assume that the reporting protocol remains entirely unstructured, and propose to collect additional meta-data about the reporting process that would help in the interpretation of citizens' reports. We focus our attention on data that directly corresponds to observers' considerations related to decisions regarding: monitoring, detecting and identifying and recording and sharing species observations. Semi-structuring of opportunistic citizen science protocols is essential for mitigating various biases, such as the ones associated with estimating sampling effort, which is required for studying species richness (Walther and Martin, 2001) and abundance (Delabie et al., 2000; Aagaard et al., 2018). Doing so has the potential to dramatically improve the scientific value of citizens' reports (Kelling et al., 2019).

Broadly speaking, data regarding observers' decision-making process could be gathered either by directly asking observers (using a prompt in the reporting application, an interview or a questionnaire) or alternatively, by using a data-driven approach to approximate observers' considerations through their reporting activity. Here we present an approach that is primarily based on a short questionnaire; later in this paper, where we discuss future research directions, we will present opportunities for replacing the questionnaire with a data-driven approach. In presenting the structure of the questionnaire, we will follow the three phases of our proposed framework (**Figure 1**), and pay particular attention to considerations that are pertinent to wide-scope and evidence-based projects.

Monitor

Observers' choices regarding what, when, and where to go out for a monitoring trip are evident through their actual reporting activity (Boakes et al., 2016). We loosely use the term "monitoring trip" to include any trip that yields reports on observations, including observations that are taken when the initial purpose was not monitoring, such as encountering wildlife when commuting. The location of one's observations is commonly recorded in most monitoring applications, particularly in evidence-based platforms, such as iNaturalist, that rely on photos' automatic geo-tagging. Similarly, observers' choices regarding when to monitor are reflected in the times when observations were taken (Callaghan et al., 2019). However, decisions regarding what species or taxon to record cannot be directly deduced from one's reporting patterns, as species reports are also influenced by a variety of species- and observer-related considerations (see below). Thus, in order to better understand observers' choices regarding monitoring decisions, the questionnaire includes the following question: "*In your nature monitoring excursions, do you actively go out seeking a particular species? if yes, what are the species, or species categories, that you usually target?*".

Detect and Identify

The literature discusses the factors affecting species *detectability*, paying particular attention to species-related features (e.g., animal size, fur pattern) and behavior (e.g., diurnal or nocturnal) (Boakes et al., 2016; Robinson et al., 2021). Nonetheless, observer-related factors also influence the ability to detect a species, namely: the amount of attention devoted to monitoring, observers' expertise and the equipment used. Wide-scope and opportunistic platforms such as iNaturalist, relay on reports taken by observers which are heterogeneous in terms of the attention they devote (some report when on leisurely nature strolls, others actively seeking wildlife) and their equipment (some use smartphones, others professional cameras with powerful zooming capabilities)[3] (Kirchhoff et al., 2021). The ability to identify species is most critical in expertise-based platforms (e.g., eBird), in contrast to evidence-based platforms where the observer's initial identification is less critical, as the community is involved in the identification process based on the photos taken. Hence, expertise-based platforms collect meta-data of observers' expertise, or alternatively, use data-driven proxies to gauge expertise (Barata et al., 2017; Johnston et al., 2018; August et al., 2020). Thus, we suggest to include in the questionnaire questions pertaining to observers' equipment ("*What type of equipment do you use for detecting species?*") and their context when making observations ("*What sort of activity are you regularly engaged in when making observations (e.g., work, leisure, actively seeking wildlife*"). In addition, we suggest to include in the questionnaire the question: "*What is your level of expertise in the various species categories that you report on (e.g., plants, insects, birds, mammals)? what is your source of expertise (e.g., formal education, practice, self-taught)?*".

Record and Share

The literature pays little attention to considerations pertaining to the decision whether to record and share an observation, perhaps because much of it has focused on birdwatching, where (a) the process of recording what has been identified is rather simple, and (b) observers go on excursions with the intent of reporting their observations. Wide-scope and evidence-based projects, on the other hand, differ in two fundamental ways. First, sharing of the observations once it has been identified and documented may not be simple, especially in platforms that require evidence (i.e., photos) and when one is using a professional camera (rather than the smartphone app), requiring the manual upload of the photos through a website. Second, observers make choices about what they perceive as important to record. For example, observers may have a stronger affinity to certain species and others may consider rare species as more important to document (Welvaert and Caley, 2016); in both cases, such considerations result in that many of the observations are neither recorded nor shared. To capture these preferences, we included in the questionnaire two types of questions. The first asks observers to specify their preference and affinity to a series of species (either using a Likert scale, or in ranking the species by the observer's preference). The second asks observers "*What is the likelihood that you will detect a _____ and opt not to record it [remote, low, about even, high, almost certain]?*". To limit the effort required for filling-in the questionnaire, we propose that both these questions be limited to a restricted set of species. Later, when discussing the practical implications of our study, we discuss the ability to extrapolate this information to other species.

In addition to observers' considerations regarding what, when and where to observe species, data regarding the *effort* or time invested in each observation excursion is essential for utilizing citizens reports for scientific purposes (Delabie et al., 2000; Walther and Martin, 2001; Geldmann et al., 2016; Aagaard et al., 2018; Boersch-Supan et al., 2019). Quantifying effort is crucial information required for ultimately assessing species richness or abundance. Effort could be estimated automatically from reporting logs (e.g., the time from first to last observation on a particular day) or obtained directly from observers (e.g., indicating in the monitoring app when the excursion begins and ends) (Kelling et al., 2019). Alternatively, we propose to include in the questionnaire a question about the time typically spent in observation excursions, for example by indicating the percentage of excursions that are: less than an hour long, 1–2 h, 2–4 h, and more than 4 h.

DEMONSTRATING OUR PROPOSED FRAMEWORK USING DATA FROM AN INATURALIST PROJECT

In this section we report on a small-scale empirical study that is intended to illustrate the questionnaire's ability to capture the factors driving observer-based biases by employing data from a local project on the iNaturalist platform.

Research Setting

The setting for this study is "Tatzpiteva" (in Hebrew, a portmanteau of "nature" and "observation"), a citizen science project that allows observers complete reporting autonomy, namely allowing them to report on any species they choose, at any place or time, while providing limited guidance and

[3]In contrast, the observers contributing to species-focused applications such as eBird are more homogeneous: they commonly share the goal of seeking observations, are watchful when observing nature, and often use professional photography gear.

direction (i.e., the need to accurately represent species spatio-temporal distribution). Hence, such a setting is likely to reveal a broad range of observer-based considerations and biases. Namely, the observation protocols are opportunistic–as opposed to systematic monitoring that is commonly used in scientific research. Tatzpiteva, launched in January 2016, is a local citizen science initiative focused on the Golan region in northern Israel, a rural area the size of 1,200 square km, where the dominant land use are open rangelands and residents live in small towns and communities. The project is operated by the Golan Regional Council together with the University of Haifa. Observations are reported by a local community of volunteers. Tatzpiteva employs the iNaturalist[4] online citizen science platform (Wiggins and He, 2016; Kirchhoff et al., 2021), whereby observers use a mobile phone (both Android and iPhone applications) and a web site. Observations are recorded using a camera and then recorded (or uploaded) to the online database; when using a smartphone app recording and sharing are performed simultaneously, unless limited internet connection delays upload; and when using a standalone camera to record observations, reporting to the website is performed at a later stage. The observer may choose to identify the species in an observation; in any case, the observation is later subject to a community-based validation process, intended to accurately identify the species. As of February 2020, approximately 33,000 observations have been reported on Tatzpiteva by 400 residents of the Golan, making up roughly half of all iNaturalist observations in Israel.

Data for this study was collected through a questionnaire that was administered by the research team, and data of observers' activity was gathered through iNaturalist's data export utility[5]. The questionnaires were sent to the 38 members comprising the local community's core: all participants contributed a minimum of 25 observations and 8 were formally assigned "curator" privileges to the Tatzpiteva project. Twenty-seven responses were returned, where survey participants accounted for 82% of the recorded observations in this project. Insights were gained by linking observers' activity patterns to their responses in questionnaire and interviews, where participants were given the option to provide their iNaturalist user name, assuring them anonymity (all participants have consented).

Illustrating Observers' Considerations and the Resulting Biases

In this section we seek to demonstrate observers' considerations by showing patterns that link their responses to a questionnaire and the observations they reported to the online system. The section is organized according to the proposed three steps in observers' decision-making process: *monitor*, *detect and identify* and *record and share*. Our aim is to illustrate the concepts from our framework and make them concrete, rather than to provide strong statistical evidence for trends in species behavior or to draw conclusions regarding causality. Our analyses combine data from observers' questionnaire and from iNaturalist logs of reported observations. In highlighting patterns that reflect observers' considerations, we attempt to informally control for other potentially confounding factors, namely species' characteristics and behavior. For example, when illustrating observers' preference for species, we compare the records of two observers who live in the same village, and mostly report from the immediate vicinity of their residence at similar times (and thus are likely to encounter the same species), use similar equipment (controlling for differences in detectability) and have similar level of expertise (controlling for the ability to identify species).

Choosing Where and When to Monitor

When questioned about monitoring decisions, observers' answers exhibit considerable variability, whereas some are going on monitoring excursions seeking to record specific species, others simply go out to nature with no particular target in mind. The differences in observations' location, as illustrated in **Figure 2**, hint at observers' spatial preferences.

A key factor determining where observers monitor is the proximity to their residence. Observers' residence data was obtained from the questionnaire, given that this data is not recorded on iNaturalist. As illustrated in **Figure 3** below, the majority of observations are in locations close to one's residence, with 32.5% of observations are within 5 km from residence and 18% within 1 km from residence.

The hour in the day when observations are recorded exhibit a bell-shaped distribution, with the mean at around noon time. Observers also differ in terms of the time they choose to monitor, as illustrated in **Figure 4** below. When considering species daily activity patterns, it is clear that observers' choice when to record influence the species they encounter.

Detecting and Identifying a Species: Observers' Expertise and Photography Equipment

iNaturalist employs a communal identification process, whereby observations move up a quality scale as more community members confirm the identification (independent of members' expertise or tenure in the community), where the highest quality grade is "Research Grade." Hence, if a research or a government agency were to employ an analysis only observations that have reached Research Grade status, the expertise of the person that made the observation are less relevant. Nonetheless, in the cases when all observations are used in an analysis independent of their research grade, the observer's level of expertise may become more important. Our analysis sought to identify whether experts' observations are of a higher quality. We compared the percent of observations to reach a Research Grade between experts and non-experts. Within the Tatzpiteva project, "curator" privileges are given to some of the experts[6], with the main responsibility of helping correct the identification of others' observations.

[4]https://www.inaturalist.org/

[5]https://www.inaturalist.org/observations/export

[6]It is important to draw the distinction between project-level curators (as in Tatzpiteva) and platform-level curatorship on iNaturalist. The latter entails administrative responsibilities, rather than domain-specific expertise. Namely, curators on iNaturalist employ iNaturalist's tools to manage taxonomy and assist with various flags.

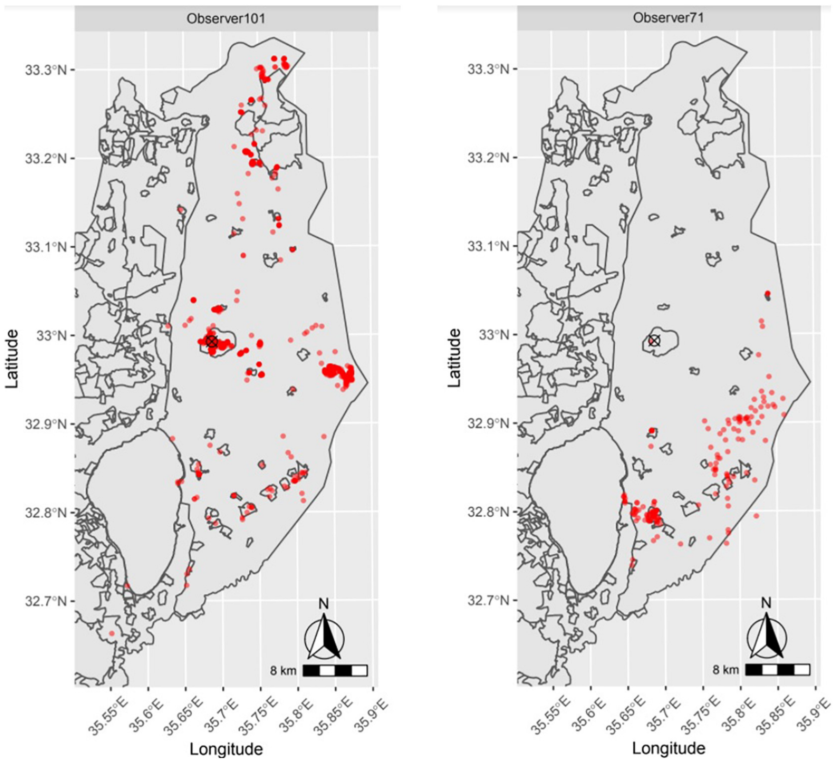

FIGURE 2 | The geographical spread of observations for two observers who use similar photography equipment and live in the 314 same town (marked by a).

We found that whereas 69.5% of the observations by non-experts' (i.e., regular community members) reached Research Grade status, the percentage of curators' observations to reach this quality grade was substantially higher: 87.9%. Furthermore, experts also contributed significantly to the quality assurance process of others' observations: 81.1% of the observations that received a feedback on species identification by an expert reached Research Grade, compared to 53.0% that reached this quality grade after receiving feedback from non-experts.

The questionnaire responses revealed that a key factor affecting observers' actions is the equipment they use, where the primary distinction is between those using smartphone camera (observation instantly uploaded to iNaturalist) and others who use a professional camera with powerful zoom capabilities (observations uploaded later to the web site). Those using professional cameras more often report on birds' observations, whereas those using smartphone cameras are more likely to report on reptiles, arachnids and insects (**Figure 5**). Interestingly, no differences are seen in the likelihood of reporting mammals.

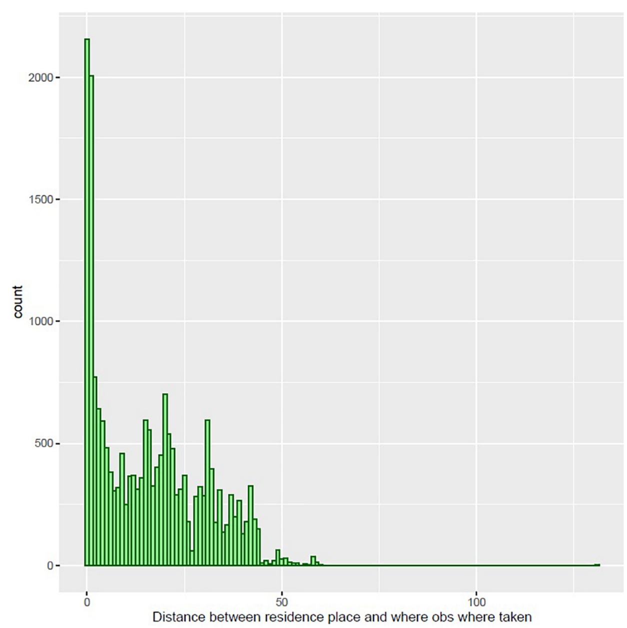

FIGURE 3 | Observation count by the distance (in km) from the observer's residence.

Observers' Decision What Observations to *Record and Share*

We studied observers' questionnaire responses regarding *recordability*: the likelihood of detecting and identifying a particular species, and their decision not to record the observations. We compared observers' responses regarding recordability for four species—gazelle, wild boar, jackal and tortoise—to their iNaturalist reporting patterns. We found that recordability is strongly correlated with observers' count of reports, as illustrated in **Figure 6** below. When comparing recordability to iNaturalist observation logs for each species distinctively, we found that the correlation persisted for each of the four species.

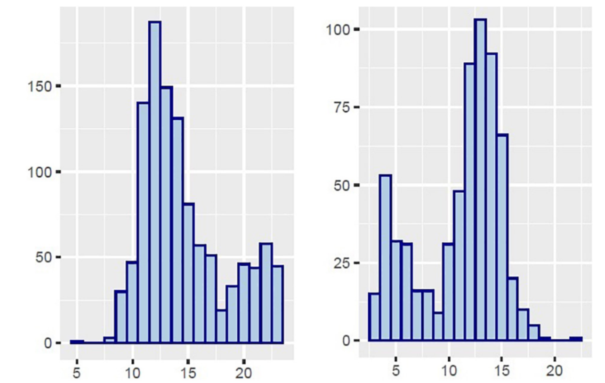

FIGURE 4 | The percentage of observations per the hour of the day for two different observers: Observer 101 (left; active middays and nights) and Observer15 (right; active early morning and middays).

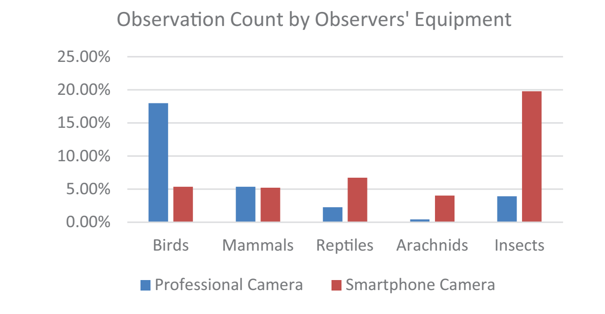

FIGURE 5 | Differences in species distribution between observers using smartphone camera ad those using a professional camera.

Observers' Preference for Species

A key insight from the questionnaire is that observers' preference for species or a taxon is a factor that influences all three steps of the reporting process. These preferences may reflect an emphasis on communal goals (e.g., preferring flagship species, such as gazelles in Israel), one's hobby, an inclination to favor rare species, or the observers' expertise. Regardless of the source of these preferences, they affect decisions regarding *monitoring*, *detection and identification*, and the *recording and sharing* of the observation. When deciding to *monitor*, the observer may choose a place and time where the species of preference is most likely to appear. Similarly, the preference to a particular species may influence observers' attention (Dukas, 2002) and thus their ability to *detect and identify* the species. Lastly, observers may choose to *record and share* their species of preference more often than recording other species they encounter.

The questionnaires revealed that most often peoples' preferences are articulated at the taxon level and less commonly they have a special affinity to a particular species. The differences in observers' reporting patterns, as illustrated in **Figure 7**, hint at preferences for species categories.

Delving deeper, we sought evidence in the data for observers' preference for particular species, focusing on 9 quadruped species that are common in the region: Jackal, Wild Boar, Tortoise, Porcupine, Mole Rat, Hedgehog, Fox, Gazelle, and Mongoose. We compared the observes' reports against the questionnaire data regarding their affinity to the 9 species. Looking at the patterns for individual observers, we note substantial differences: for some the affinity to species is correlated with the observation count (**Figure 8**, left side), whereas for others there is no evidence for such correlation (**Figure 8**, right side). Interestingly, differences were also observed between species. For some species (e.g., wild boar) there is an evident relation between observers' affinity and their reporting patters, whereas for others no such relation is observed (mole rat).

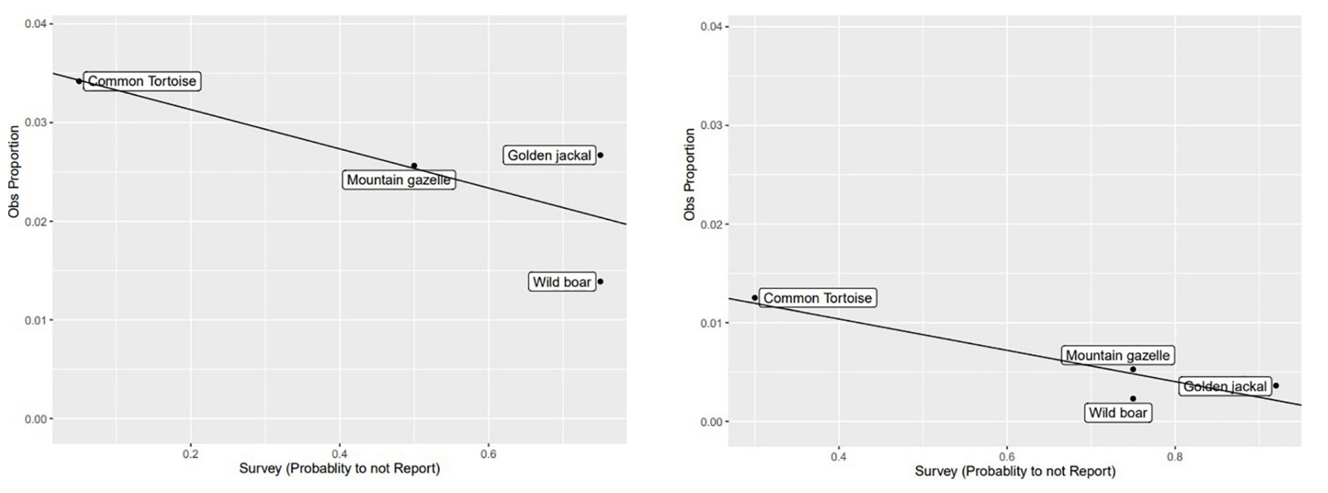

FIGURE 6 | Compared observers' questionnaire responses regarding recordability (*X*-axis) to their observation count (in percentages; *Y*-axis).

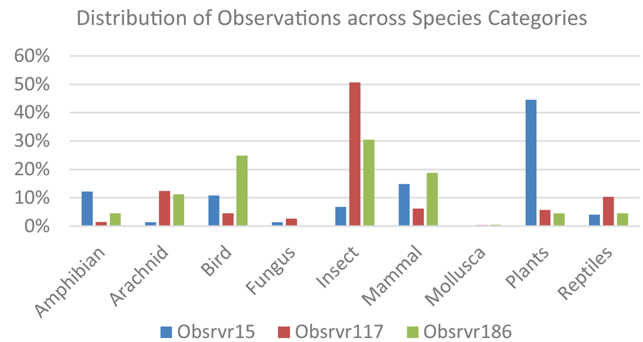

FIGURE 7 | Distribution of observations across species categories for three observers who reside in the same settlement and use similar photography equipment.

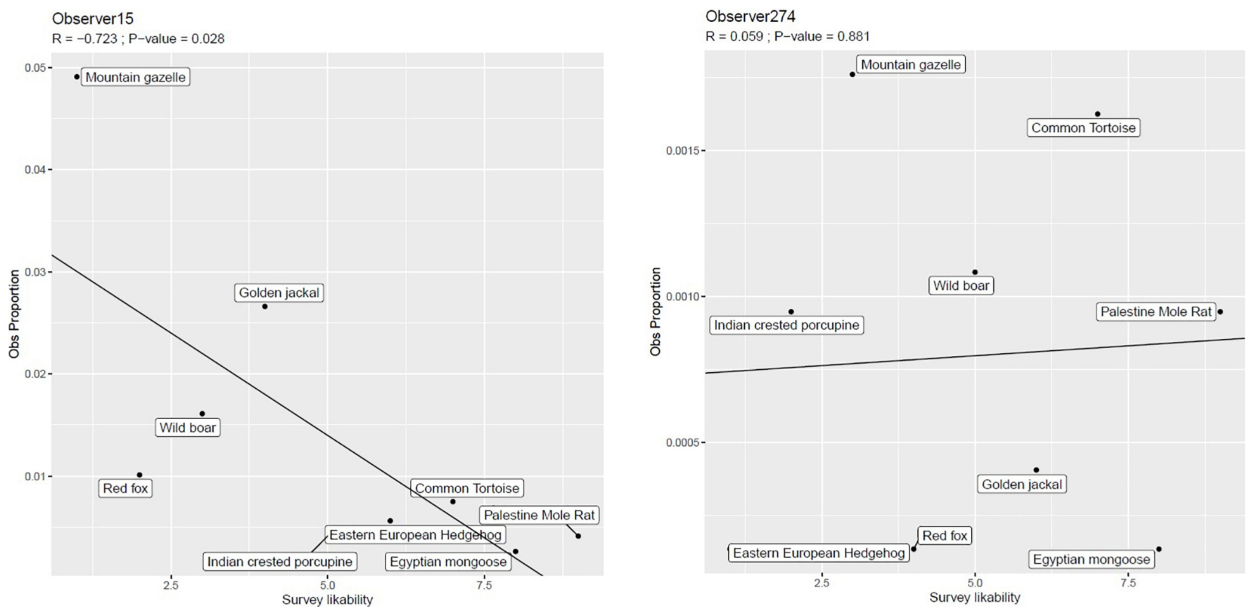

FIGURE 8 | Observation count by the observers' preference ranking of species (low is most preferred) for two observers. On the left, Observer15 with a clear association between preference and observation counts; on the right, Observer274 with no relation between preferences and observation count.

DISCUSSION AND CONCLUSION

Citizen science is widely used for biodiversity monitoring, commonly relying on unstructured monitoring protocols (Pocock et al., 2017). Notwithstanding the potential of unstructured citizen science to engage the public and to collect large amounts of biodiversity data, observers' make various considerations regarding what, where and when to monitor, and these considerations aggregate into biases, whereby the archive of citizens' reports does not reflect the actual species' spatio-temporal distribution in the environment (Leitão et al., 2011; Tulloch and Szabo, 2012; Isaac and Pocock, 2015; Boakes et al., 2016; Neyens et al., 2019; August et al., 2020; Robinson et al., 2021). Our focus in this article has been to provide a framework for collecting meta-data which will facilitate more sound statistical analyses of the data. Specifically, our focus was on the biases in the data caused by variation in the observation process. We maintain that by semi-structuring unstructured citizen science data it may be possible to engage volunteers in citizen science monitoring through broad participation, while gathering sufficiently robust data which will enable rigorous analyses and allow meeting scientific objectives.

This study adds to the literature in the area by enhancing our understanding of observer-based biases in citizen science for biodiversity monitoring. Specifically, this study makes three contributions: (I) conceptual, by developing a framework of observers' decision-making process along the steps of monitor–> detect and identify–> identify–> record and share, pointing to the considerations that take place at each step; (II) methodological, by offering an approach for semi-structuring unstructured monitoring approaches, using a targeted and focused questionnaire, and (III) empirical, by illustrating the questionnaire's ability to capture the factors driving observer-based biases.

An important contribution of this study is in conceptualizing observers' participation in citizen science as a sequential decision-making process. Prior studies have offered of conceptualizations of citizen science projects, by offering a variety of typologies, for example distinguishing between unstructured, semi-structured and structured monitoring protocols (Welvaert and Caley, 2016; Kelling et al., 2019), whether reporting is intentional or not (Welvaert and Caley, 2016), and classifying projects based on their organization and governance (e.g., the degree of citizen involvement in the scientific project) (Cooper et al., 2007; Wiggins and Crowston, 2011; Shirk et al., 2012; Haklay, 2013). Other conceptualizations categorize observers based on their reporting activity signatures, or profiles (Boakes et al., 2016; August et al., 2020). Here we take a somewhat different approach by offering a process-based framework that considers an individual observer's decision-making steps. Namely, we propose a formal structure to the reporting process, which follows several cognitive stages, beginning with the decision to leave one's home to monitor and ending in the decision to press the "report" button. From a statistical perspective, our framework suggests that observers' decision-making process could be represented trough a sequence of conditional probabilities for observes' actions: (1) the likelihood of monitoring a particular species at a given place and time; (2) the likelihood of detecting and identifying a species, conditional on monitoring that species at a place and time; and (3) the likelihood of recording and sharing a species' observation, conditional on detecting and identifying the species. A statistical approach for mitigating observer-based biases, hence, should account for this sequence of probabilities.

The proposed framework is based on a synthesis of the literature, and many of the concepts we examine have been discussed in prior works (Kéry and Schmid, 2004; Kelling et al., 2015, 2019; Welvaert and Caley, 2016; Wiggins and He, 2016). Thus, the value of this framework is in offering a novel perspective for organizing these concepts in a manner that highlights the factors underlying observer-based biases. Whereas our framework is applicable to most, if not all, biodiversity monitoring projects, some important differences are worth noting. For example, the *identify* step in our framework precedes an observer's decision of whether to *record and share* an observation, but observers in iNaturalist often report an observation absent of an identification (e.g., with the goal of learning).

While much of the research to date on biases in citizen science has focused on expert-based semi-structured projects (Sullivan et al., 2009; Fink et al., 2010; Johnston et al., 2018; Kelling et al., 2019), we focus here on wide-scope evidence-based opportunistic citizen science projects. This shift in scope brought into light less explored biases. Namely, prior research has focused primarily on biases related to detection (i.e., *detectability*; e.g., vegetation and species traits) and identification of observations (e.g., observers' expertise), whereas our study emphasizes other factors. Specifically, given the great variability in the observer population and the tools they use to collect evidence, has called into attention observers' practicalities related to detection and identification, namely observers' photography equipment: those with professional cameras are able to better identify species. More importantly, treating the step of recording the observation as a distinct phase has underscored the importance of *recordability*: observers' perceptions regarding what is important to record and the effort involved in uploading and sharing observations (more onerous for photos that are uploaded to the website after-the-fact) influence what observations end up in the database. To the best of our knowledge, this is the first study that identifies *recordability* as a distinct construct. The ability to capture observations' recordability may prove essential in developing methods for mitigating observer-based biases (see below). It is important to note that an observer's *recordability* for a species may change over time; for example, the observer may always report the first gazelle observations of the season, but after encountering many gazelles, may opt not to record their observations. Another important insight that emerged from our study is that the preference to a particular species or taxon is an overriding factor that drives an observer's decisions throughout the three reporting stages we defined.

A second contribution of this study is in the methodological approach for semi-structuring unstructured citizen science data. We propose questionnaires that are highly focused and targeted at revealing the factors that underlie observers' decisions regarding what, where and when to report. In contrast to traditional questionnaires that are designed to capture well-established psychological constructs, our questionnaire is shaped by practical considerations, especially designed to unravel the factors influencing observers' decisions-making process. We expect that the questionnaire information could later be used for mitigating observer-based biases, thus making the citizen science data usable for scientific purposes. The proposed questionnaire somewhat resembles the metadata that is collected in semi-structured projects such as eBird (Sullivan et al., 2009). For example, Kelling et al. (2019) has recently proposed a set of metadata that should be collected in semi-structured projects, including data that is often recorded automatically (time, location, observer's identity) and data that requires additional data entry (duration or effort, method of surveying). However, we attempt to capture, beyond this metadata, observers' preference for species/taxon, their particular domain of expertise and considerations related to the decision of whether to record the observation (i.e., recordability). To the best of our knowledge, this is the first study to propose methods for estimating the factors underlying the decisions of what observations are reported.

We also contribute to the literature by empirically illustrating observer-based biases and by linking observers' considerations to their actual reporting patterns. Prior studies have analyzed the spatial distribution of observers and their observations (Isaac and Pocock, 2015; Boakes et al., 2016). Here, the questionnaire offered unique data about observers, which we utilized in comparing iNaturalist reporting logs to observers' preference for species and to their likelihood of reporting certain species once detected, allowing us to expose observers' considerations and biases in novel ways. For example, we show that the observers' reporting patterns are often correlated with observers' preference for species and demonstrate that observers' self-reported recordability data (i.e., the likelihood of recording or not, when detecting a particular species) are indicative of their actual reporting patterns.

The proposed approach for semi-structuring unstructured monitoring protocols offers important implications for researchers and government agencies that are interested in utilizing citizen science data for analyzing trends in species spatio-temporal distribution. As has been suggested in prior studies, an understanding of observer-based biases may be valuable in directing the observers in a way that mitigates theses biases. For example, citizen observers may be guided to report on all species, independent of their rarity, or even be directed to monitor under-monitored areas (Callaghan et al., 2019). Alternatively, our proposed approaches for estimating biases could be leveraged by statistical methods that attempt to correct biases in citizen science data (Wikle, 2003; Royle et al., 2012; Dorazio, 2014; Koshkina et al., 2017; Aagaard et al., 2018; Horns et al., 2018; Boersch-Supan et al., 2019; Neyens et al., 2019). In particular, we foresee that data regarding observers' preference for species or recordability will be incorporated into statistical models that utilize citizen science data. To infer the ecological process from citizen science data it is essential to account for species' characteristics, in particular detectability (beyond the observer-based biases that were discussed above). We note that detectability is a complex construct, as it depends on the landscape characteristics, such as vegetation cover, weather conditions and species' morphology. Our findings point to much variability in peoples' responses: for some, the preference for species is reflected at the taxon category, whereas others preferences are also manifested within a taxon category (e.g., strongly prefer a gazelle over a jackal). Moreover, the extent to which a preference for species predicts observers' reporting pattern differ between species (the relation is evident for wild boar much more than it is for mole rat). These variations suggest that any bias-correction statistical model should include observer-specific and species-specific parameters.

Our proposed approach comes with its limitations, opening the door for future research in the area. Most importantly, our approach for semi-structuring unstructured citizen science data requires that a questionnaire be administered to collect data regarding observers' considerations. Whereas the questionnaire was designed to be concise, many participants may choose not to complete it. This limitation may be addressed by future research in different ways. For example, the questionnaire may target the most active observers, thus cover a large portion of the observations in the area. In addition, we believe that statistical models may be able to extrapolate from the information about few observers, and their reporting patterns, to other observers for which this information is not available. Alternatively, it may be possible to develop methods for automatically inferring observers' considerations. For example, prior studies have suggested that observers' reporting patterns may be indicative of their preferences or expertise (August et al., 2020). However, given that citizens' reports are used as evidence for species distribution, we caution against using this same data for proxying observers' considerations (and accounting for biases), as such an approach may result in circular logic. Perhaps other types of data—e.g., from community discussion forums and the communal quality assurance process—are better suited for estimating observers' characteristics such as their preference for species. Future research could also investigate ways for improving the questionnaire, for example by utilizing methods from behavioral psychology to more accurately represent observers' preferences. Another limitation of our study is that it was restricted to a particular region (northern Israel) and a single citizen science platform (iNaturalist). Although the empirical data was merely employed to illustrate the biases, it is possible that an analysis of other regions and projects would reveal a different array of observer considerations and biases. Future research could also conduct large scale empirical research so as to statistically analyze the extent to which various observer considerations predict their reporting patterns, attempting to assign weights to these various biasing factors (Robinson et al., 2021). Such future research would need to operationalize some of the constructs that were loosely defined in this paper, for instance what constitutes "a region."

An additional interesting avenue for future research is to investigate the motivational processes underlying observers' considerations. Prior research on the motivation for participation in citizen science projects (Nov et al., 2014; Tiago et al., 2017) has employed generic frameworks such as Self Determination Theory (Ryan and Deci, 2000) or the model for collective action (Klandermans, 1997). We suggest that future research move beyond these generic conceptualizations to studying the specific motivational factors that are directly linked to observer-based biases. For example, the affinity to a particular species may be linked to a fond childhood memory, or alternatively, to an identification with national symbols. Similarly, recordability may be linked to observers' preference for species, or alternatively, to animal-related features such as shyness and the speed at which it flees when encountering humans. We believe that a deeper understanding of the motivational dynamics underlying observers' behavior could yield insights that may be relevant for mitigating the biases.

In conclusion, we believe that citizen science has the potential to become an important approach for biodiversity monitoring, which will overcome the limitations of traditional monitoring methods. Unstructured CS data reflects both the ecological process that determines species presence in a given location and observers' decision-making process. Hence, for citizen science's potential to materialize, it is essential that we deepen our understanding of the various biases that are associated with observers' considerations, and that we identify ways for accounting for these biases in statistical models of species distribution. We hope that this study will encourage future research on the development of tools that assist scientists' efforts for tracking trends in the worlds' biodiversity. By enhancing our ability to detect such trends in species population, we may be able to intervene promptly, to protect the environment.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

OA led the conceptual development. DM led the empirical analysis. Both authors contributed to the article and approved the submitted version.

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Social and Ecological Elements for a Perspective Approach to Citizen Science on the Beach

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Sandy beaches are ecotonal environments connecting land and sea, hosting exclusive resident organisms and key life stages of (often charismatic) fauna. Humans also visit sandy beaches where tourism, in particular, moves billions of people every year. However, instead of representing a connection to nature, the attitude toward visiting the beach is biased concerning its recreational use. Such "sun, sea, and sand" target and its display seem to be deeply rooted in social systems. How could scientists engage the newest generations and facilitate an exit from this loop, fostering care (including participative beach science), and ultimately sustainable sandy beach use? To tackle this question, we applied the concept of social–ecological systems to the Littoral Active Zone (LAZ). The LAZ is a unit sustaining beach functionalities, though it includes relevant features making a beach attractive to the public. Out of the analysis of the system LAZ in its social and ecological templates, we extracted elements suitable to the planning of citizen science programs. The perspective of leverage points was integrated to the needs identified in the analysis, through reconnecting–restructuring–rethinking the components of the system. Two cross-cutting approaches were marked as important to social and ecological designs and break through the dominant perception of beaches as mere piles of sand: the physical dimension (LAZ) of the beach as a unit, and the use of communication through social media, suitable to both monitoring and scientific data collection, and to data communication and hedonistic display of a day on the beach.

Keywords: beaches, social ecological systems, leverage points, attractiveness, Littoral Active, Littoral Active Zone, recreation, leisure

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INTRODUCTION

Sandy beaches are ecotonal environments, meaning they connect the land and sea and provide a range of ecosystem services—from nutrient cycling to shoreline protection, to uniquely adapted biodiversity (McLachlan and Defeo, 2017). The perception of those diverse ecosystem services, however, often remains unseen due to the focus on the cultural ecosystem service of recreation. Such bias led to a short-term vision in beach management at the expense of the sustainability of their use and maintenance of the processes they host (Butler, 1980 for the life cycle of a touristic area; Fanini et al., 2020a for natural risks enhanced by human overuse). Calls for attention to the system "beach" by sandy beach ecologists remained unattended (Defeo et al., 2009; Dugan et al., 2010), in spite of the paramount economic relevance depending on the availability of an ecologically healthy beach. Sandy beach ecologists hypothesized that the perception of beaches as mere piles of sand and the scarce appeal of resident beach fauna (semiterrestrial crustaceans, insects, and worms) was at the base of such lack of attention, hampering any grassroots movements toward the conservation of beaches—even in case of endemic fauna (Harris et al., 2014). The periodic occurrence of charismatic megafauna seems to be the only triggering factor of actions (Maguire et al., 2011). However, actions not supported by a systemic view risk to remain limited in vision and short-termed, such as protecting the nests of sea turtles rather than protecting the nesting habitat as a whole.

Beaches are extremely attractive to people worldwide. On social media, hashtags related to the beach raise huge attention, e.g., on Instagram (hereafter used as the main example due to its strong association of images, short text, and hashtags), #beach reaches 265M posts, with #sandybeach 612K, and #shinglebeach 10K, but also when using other languages, #praia is 29.6M and #playa 27.4M—data retrieved March 31, 2021). The vast majority of the posts is related to recreation and business and reflects the general perception and attitude toward the "sun, sea, and sand" model. Especially on social media, there is an added element, i.e., to show as a trophy: the own presence on a desirable beach (Baldacchino, 2010). Yet, when studying what makes a beach attractive, features intrinsically interconnect attractiveness to geomorphology and ecology (e.g., Anfuso et al., 2018). We do, therefore, believe that making such a connection explicit will unleash huge potential for engaging users. Special attention goes to social media-active generations, because of the visual impact and attention that the features of a healthy beach can raise. In this viewpoint, we intended to extract key variables from the sandy beach research study and make them pillars for citizen science actions, viable for societal mainstreaming through media.

PERSPECTIVES

Sandy Beaches as Systems

To delimit the social–ecological system, a first step is to identify it physically. The concept of Littoral Active Zone (LAZ), i.e., the dimension across land and sea where dynamic exchanges of energy and material occur (Tinley, 1985), was first proposed as a budgetary approach to estimate the amount of sand available on the littoral. Such clear functional dimensionality allowed the extension of the concept to the processes encompassed within and finally its inclusion in a social–ecological perspective (Defeo et al., 2020). Most importantly, the use of the LAZ concept allows the identification of a specific system boundary, expected to react as a whole to environmental drivers and threats, hence a suitable unit for actions of research and management (Fanini et al., 2020b). Our perspective relates to the extraction of features from sandy beach research studies, which are as follows: (1) common to both ecological and social templates of the LAZ, (2) relevant to a long-term vision, and (3) easy to share *via* images and short text—as these are most common actions related to information mainstream *via* social media. Given those characteristics, we proposed them as operational tools for conservation support to beaches and monitored by citizen scientists, with specific attention to generations Y and Z as both users and drivers of change.

We applied the conceptual framework of social–ecological systems (Berkes and Folke, 1998) to the LAZ (**Figure 1**), allocating within the template elements suggested in literature reviews and meta-analyses related to ecological paradigms, the attractiveness of a beach, and suitability and potential for conservation.

Key features of the LAZ system relate to the ecological mesoscale, which is of particular importance for the macrofaunal diversity, though they connect ecological and social templates, being the very background for the attractiveness of a beach. For instance, the variable "beach width," a key for habitat availability, biodiversity, and populations traits (Barboza and Defeo, 2015), also represents the available space for recreation and matches the concept of "beach" by the lay public. Variables such as water and sand color (Mestanza-Ramón et al., 2020) are rooted in the "beach imaginary" and partly overlap with the "sun, sea, and sand" model. They are featured in social media profusely and represent desirable beaches, though they are connected to dynamics such as erosion, contamination, integration of infrastructures, accessibility, and safety.

Following this conceptual organization, it clearly results that most elements suitable for connecting beach users to the beach as a system through citizen science actions belong to the LAZ physical and biological stocks. Research studies in beach ecology can provide a sound background on stocks and also standard methods to measure and quantify them. For instance, the attitudes of beachgoers also involve items from the social template. In this aspect, users seem ready to consider both templates—perhaps even a step ahead of scientists. Also, beach users can easily connect to other components of the system, in visualizing related information and returning benefits to scientists, citizens, and to sustain governance as an ultimate goal.

Beach Citizen Science Projects

Recent reviews of marine citizen science projects pointed out the fact that the beach is an easy and cost-effective location for citizen science actions (Garcia-Soto et al., 2021). Projects span from species-specific focus, usually tackling the habitat where iconic species nest (birds and turtles), live (insects and ghost crabs), or spawn (fish), but also in fewer cases and in a country-specific fashion, dealing with broader scales, biodiversity, and geomorphology (e.g., on wrack-associated fauna and shoreline erosion, respectively) (Earp and Liconti, 2020). The common background to most projects remains the LAZ, with the single beach as a unit, and the focus on physical and biological stocks. In these contexts, the inclusion of sensitive features from the social template would start building links across science and society, given that the very same unit is not only where ecological processes occur but also the area experienced by beachgoers and the unit under management by local authorities.

Regarding the tools available, the attention toward mobile apps and platforms is clearly raising, driving toward a "socio-technical approach," as summarized by Sturm et al. (2017),

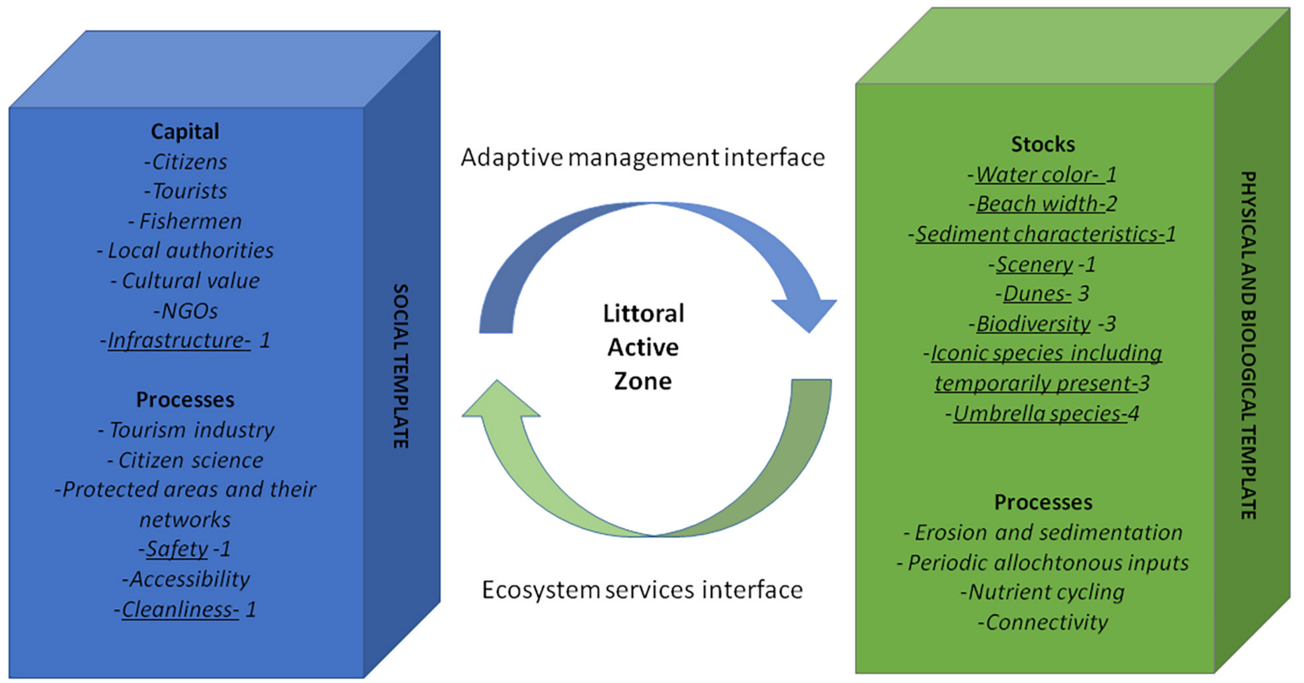

FIGURE 1 | Readapted from Fanini et al. (2020b) using the standard color-coding (blue for social template and green for the ecological template; Bretagnolle et al., 2019). Features related to attractiveness, relevance to the preservation of functionality, and easiness to report *via* pictures or short texts are underlined within each template. 1. Anfuso et al. (2018); identification of five main features making a beach attractive. 2. Defeo and McLachlan (2013); relevance of beach width, beach slope, and grain size to biotic processes. 3. McLachlan et al. (2013); identification of criteria for the assessment of a beach viability for conservation actions. 4. Costa and Zalmon (2021); identification of beach umbrella species.

allowing to keep the connection between citizen science principles (see 10 principles of the European Citizen Science Association[1]), the social background of participants and the rapidly growing range of technological tools. Finally, the success of citizen science projects will still rely on the strength of the message and its social–ecological impact. We believed that social media, where the beach has a widespread presence already, would represent a source of paramount relevance to mine into. Emerging approaches such as netnography (Kozinets, 2019), browsing for qualitative inter-connections within social media, would greatly support advances in this sense. Queries related to images, toponyms, and co-occurrence of hashtags would relate physical and biological beach stocks and ideally highlight their cultural value and attitudes of users. New tools available would sustain the restructuring of meanings of system elements, breaking through old perceptions and attitudes.

Stories From Beached Plastics, the Blue Flag, and Tourism-Oriented Platforms

Beached plastic litter as a subject of citizen science actions is worth a mention. The reaction to a littered beach is rooted on the perception of the litter as an offense (Tudor and Williams, 2003) and has a huge potential to engage and build on people active citizenship (Battisti et al., 2020). Cleanup actions are related to conservation, though can support citizen science, contribute to the research study of litter pollution on beaches and their management at different scales (Chen et al., 2020; Urbina et al., 2021). The great support of people toward cleanup movements comes from their relationship with the environment by itself and not from an awareness of preserving biodiversity. However, this indirectly benefits the entire beach ecosystem, being a great option for the purpose of conservation and maintenance of a harmonious relationship between beach users and beach nature. It also relates to LAZ features such as beach cleanliness and safety. Most widespread protocols, e.g., OSPAR (2010) and WIOMSA (Barnardo and Ribbink, 2020), are in place and offer visual manuals, as well as platform and apps support (e.g., the Marine LitterWatch app). Pictures of cleanup results are often shown on social media, especially in association with different campaigns (and huge differences, e.g., #2minutebeachclean, 152K posts on Instagram; #marinelitterwatch counts less than 100 posts—data retrieved on April 4, 2021). They are often disconnected from the beach where they proceed from. The connection of these actions to the beach as a living system (Kiessling et al., 2017) would allow going beyond the approach to beaches as "resting places" for plastic litter. The achievement of a systemic view could be improved by adding information requests, whether in pictures or short texts, from basic features from the physical and biological stock (**Figure 1**).

Initiatives to promote beach quality such as the Blue Flag (BF) are not based on citizen actions; however, the BF implementation highlighted attitudes connected to the

[1] https://ecsa.citizen-science.net/documents/#tenprinciples

promotion of a good environmental quality beach under both ecological (i.e., cleanliness of sand and water) and social (i.e., accessibility and safety) aspects. In most cases, it is progressively perceived as a touristic label (McKenna et al., 2011; Peña-Alonso et al., 2017). It is an important signal of the attention that beach features can raise and shows a promising background for the reconnection of beach users to the beach system, but it needs to be integrated by relevant literacy (a process that has to start from researchers providing literacy points). Actions specific for the association of the BF with other elements of the LAZ, such as a hashtag, strongly associated with conservation would help to inter-link components and counterbalance the current attitude to recreation as a sole driver.

An example of an interactive case, commercial and not associated with quality labels, is the platform: www.cretanbeaches.com. The identification of attractive stocks (i.e., water color, size and color of the substrate, infrastructure, accessibility, and frequentation) was applied to a local (the island of Crete) level. The site quickly became a reference for both locals and foreigners, with millions of visualizations (AR, Cretanbeaches CEO, personal communication, data from 2019). The information related to single beach proceeds from the feedback of visitors *via* multiple entries, though the dataset is lively and constantly reviewed by "peer beachgoers"—which explains the success of the website.

These experiences are powerful indicators of the potential for citizens to take on a major role when comes to provide, share, and use information about beaches in an integrated fashion [also including biotic aspects, such as the presence of threatened, endemic and/or charismatic species, and threats (e.g., fishing, vehicle traffic, and sewage disposal)]. The need to assess and follow up the process of change in a social–ecological system can be fulfilled by an approach *via* leverage points.

Leverage Points

One perspective for the comprehensive assessment based on social–ecological system thinking is the perspective of leverage points (Meadows, 1999; Fischer and Riechers, 2019). Leverage points are "places to intervene in a system" (Meadows, 1999) and are based on a hierarchical structure, from shallow (e.g., changes in parameters such as the amount of plastic at the beach or feedbacks in touristic platforms) to deep (Abson et al., 2017). Deeper leverage points are found in a system which is defined by the structure of information flows; they relate to the rules of the system and the power to add, change, or self-organize the system structure. This includes a change of mindset or paradigm shift (Meadows, 1999). Changing the system intent would hence influence its structure, rules, delays, and parameters (Abson et al., 2017; Meadows, 1999). In the case of beaches, shallow leverage points such as beach cleanups are important, especially when they are linked to deeper transformation through education and behavior change. However, the perspective of leverage points can aid to focus on the transformative potential of specific interventions, so to include actions that lead to sustainability in the long term (Riechers et al., 2021). Deep leverage points to foster a sustainability transformation relate to *reconnecting* people to nature, *restructuring* institutions, and *rethinking* how knowledge is created and used to achieve sustainability (Abson et al., 2017).

The reconnection of beach users to the beach environment beyond its recreational and temporary use will go through the recognition of the tie between beach attractiveness and preservation of its stocks, which will, in turn, keep the system functionality. The huge socioeconomic relevance of the role of beachgoers and the immediate mainstream that they might have *via* the sharing of their feedback online (e.g., Google guides), or *via* social media, can be a powerful driver for management and governance adaptation. At the same time, the basic information useful to science can be provided by such a continuous and widespread monitoring.

Restructuring of mindsets and attitudes supporting governance is the main challenge for ecologists *in primis* and relates to their ability to not only provide knowledge but also to mainstream it in a long-term vision (e.g., Otto and Pensini, 2017). The use of LAZ as social–ecological system is a frame into which novel approaches such as imaging, hashtag research study, and social-media-related actions can be integrated and harmonized, and information often embedded in academia (without enough reach) can be made explicit and usable instead. The process of restructuring does not have to be disruptive, yet old tools can be loaded with new meaning. This would span from very practical tools (e.g., the recommendation to refer to existing icons for visual communication, Sturm et al., 2017) to broaden existing perspectives (e.g., the increase in ecological insights required to shift from considering charismatic species to umbrella species, including habitat requirements, taxon congruency, and ecological interactions beyond charisma, Costa and Zalmon, 2021).

Rethinking how knowledge is created will necessarily go through the involvement of the social template, where citizen science can be used as a tool for informing the public, especially regarding the novel communication potential held by generations Y and Z. Rethinking how sandy beaches are perceived but also what academic knowledge means will challenge presumptions, expectations, and perceptions. And especially in the case of younger generations, the stakes are high and could lead to a powerful intervention to foster a rethinking of knowledge and a reconnection to the complexity of the ecosystem that is the sandy beach.

CONCLUSION

Sandy beaches hold a high potential for citizen science and citizen monitoring actions, and scientists should challenge to include the emerging set of tools for engaging young generations and sustain their shift in attitudes with a vision. The loading with the new meaning of old models would boost social and ecological governance support of such relevant environments.

We intended to conclude with a few general recommendations, to start the process of making our perspective operational.

- In line with the ECSA principles, "citizen scientists may, if they wish, participate in multiple stages of the scientific process." Following this key point, the design of actions shall include the selection of features of high interest for beachgoers, as well as the participative establishment of icons, hashtags mentioning stocks, processes, and capital. Rules for visual outcomes on social media should also be set as part of the planning of actions.
- Existing actions could add simple measurements related to the LAZ, such as beach width (using steps as a proxy of meters) or pictures of the substrate. Furthermore, beached wrack could be co-measured along with anthropogenic litter in the occasion of cleaning campaigns, with the option of developing other specific targets related to the interaction of templates (e.g., insects entrapped in bottles, Romiti et al., 2021).
- The planning in space and time of citizen science actions should consider LAZ features across templates. Information provided by citizens will return patterns across social and ecological scales, e.g., geomorphological, ecological, and managerial as well as cultural. Yet, because of its connection with the youngest generations, this information will be projected into the future. Regarding the approach to human impacts on beaches, the adaptation of the concept of gravity center (e.g., Peng et al., 2017), related to the vicinity of the LAZ to a possible impact on stock and capital, would greatly support both science and governance. Timing of citizen science actions could finally integrate socially relevant phenomena, e.g., touristic season and cultural festivals.

AUTHOR CONTRIBUTIONS

LF, MR, LC, and IZ discussed the topic and co-wrote the manuscript. LF provided drafts as background for discussion and led the redaction of the final document. All authors contributed to the article and approved the submitted version.

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Leaders Inspiring the Next Generation of Citizen Scientists – An Analysis of the Predictors of Leadership in Birding

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Citizen Science (CS) is a megatrend of the 21st century given its importance for nature conservation. CS projects dealing with birds often require knowledge and abilities to identify species. This knowledge is not easy to acquire and people often learn from leaders during field trips and lectures about birds. This emphasizes the need for leaders in ornithology. Although data of CS projects are increasing, less is known about people providing guidance and taking over leadership roles. In this study, leadership roles (leading field trips, giving lectures/presentations) are analyzed by studying demographic variables, birding specialization, and the social dimension of the involvement concept of serious leisure. Participants were recruited via many channels to cover a broad range of birdwatchers in Germany, Austria, and Switzerland who participated in the online survey. A total of 1,518 participants were men, 1,390 were women (mean age 47.7). Mean years of birding were on average 24.5. 845 persons lead at least one field trip, and 671 gave on lecture (in combination 991). Mean number of field trips led during the last 5 years was 13.43, mean number of presentations was 8.21. Persons that gave presentations also led field trips (Phi = 0.593, $p < 0.001$). However, there are still people that preferred leading field trips over lecturing and vice versa. Men more than women took over leadership roles. A binary logistic regression showed an influence of age, gender, and university degree. Social relatedness was related to being a leader, also birding skill/competence as well as self-report behavior of birding were significant predictors for leadership roles. Years of birdwatching and both commitment scales were not significant. The data indicate that more diversity in leadership roles might be beneficial with more women and younger persons.

Keywords: birding, birdwatching, citizen science, recreation specialization, demographic, gender

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INTRODUCTION

Citizen Science (CS) is considered a megatrend of the 21st century given its importance for nature conservation (Bonney et al., 2009). During CS projects, people adopt in part the status of an expert (Bhattacharjee, 2005) and their valuable voluntary contribution to science can be equal to millions of $, an amount that could not be paid by any institution (Bonney, 1991). Recruitment for CS projects often occurs by word-of-mouth or online procedures. However, inspiring and motivating the next generation of citizen scientists needs more than online recruitment, especially when participants should be retained within a program for longer time periods or when the programs are more complex and request a given level of knowledge (Wood et al., 2011). CS projects dealing with bird observations often require some knowledge and abilities to identify species (Sullivan et al., 2014; Randler, 2021a). This knowledge is not easy to acquire (Randler and Heil, 2021) and people often are accompanied by others when they start this recreational activity. The most common reason for birdwatchers to start their leisure activity (their initiation as birder) is a social reason, including family transmission of knowledge, but also teachers and leaders of excursions. Similar trigger events were often a specific travel experience and nature-related groups (for details see Randler and Marx, unpublished). This emphasizes the need for leaders in ornithology and the study of this process.

Citizen Science

Citizen Science projects are increasing in popularity in the scientific community because they enable researchers to study phenomena in nature on a large spatial scale, and also on a large time scale, given the short-time funded projects of many conventional research studies (Bonney et al., 2009). Citizen Science participants, in turn, are becoming a part of real scientific investigations. Participants in these projects gain knowledge about the specific research question, but also about scientific methods (Bonney et al., 2009). However, there is some criticism of CS projects, especially with regard to the potentially lower data quality. This can result from the fact that laypersons collect the data, while in professional science projects, experts are collecting the data (Cohn, 2008). However, this seems different in the diverse CS projects. Especially in birding, the lay persons are usually highly qualified (Randler, 2021b), and CS projects can be developed to address different levels of specialization (Randler, 2021a). Nevertheless, the aspect of data quality is related to the instruction of participants, which, in turn, focus on leaders that take over the role of instructing new adepts of birding. The recruiting process of CS participants is usually haphazard and often influenced by accident (Fischer et al., 2021), and only few studies have been carried out about the people joining these platforms and projects (Wood et al., 2011). Many of them often shortly contribute to CS projects (Parrish et al., 2019). Some projects only require a short introduction, e.g., by video tutorials, and thus relatively quickly gain participants, but most of them do not remain permanently in the program (Parrish et al., 2019). Retaining people within a program is more difficult and may depend on leaders or people giving personal guidance for such projects. Parrish et al. (2019) showed that an in-person, expert-led training session, achieved higher retention of the attendees in the program. Although data volumes of CS projects are increasing (Kelling et al., 2019), less is known about the citizen scientists themselves (but see, e.g., Jordan et al., 2011; Stylinski et al., 2020), and even lesser about people providing guidance and taking over leadership roles (see, e.g., Propst and Koesler, 1998 concerning outdoor education leadership). However, CS is typically driven by scientific professionals and experts (Bonney et al., 2016), but in many cases leaders are volunteers, especially in European ornithology. Gaining information about these people is an important task. Here, we look for characteristics of people that take over leadership in birdwatching by guiding field trips or giving lectures. Analyzing this topic is important for nature conservation to help identify key factors of leaders and to further encourage other people to participate in leadership roles.

Leadership

Leaders are influencing other people, and when people are influenced, it is a result of effective leadership (Hogg, 2010). Although there is a bulk of studies on the personal characteristics of the leaders, like the cult of personality (Pestana and Codina, 2020) or the leadership style, especially with a focus on transformational leadership (Sun et al., 2017), the focus here lies on the specific predictors that characterize a person who takes leadership in birding. In this respect, the social categorization/social identity of leadership fits best (Haslam et al., 2011; Reicher et al., 2018; Turner and Chacon-Rivera, 2019; Pestana and Codina, 2020). First, the leader is one person of the group that is best representative, second, leaders are the most important persons who are responsible for promoting the interests of the group. Third, leaders are crafting a sense of the group or are entrepreneurs of the group identity, and fourth, leaders are making the group matter (e.g., by distinctness from other groups; Haslam et al., 2011; Reicher et al., 2018; Turner and Chacon-Rivera, 2019; Pestana and Codina, 2020). Thus, the identity component is an important aspect of leadership. Pestana and Codina (2020) introduced this prototype of a leader as an in-group person, integrating the individual and the situation in terms of the mutual influence between leaders and followers. This is important to the study of birding because a person being a leader today may enable and encourage other individuals, that are primarily followers, to become leaders in the future. Therefore, leadership is a process where it is fundamental to belong to a specific group and feel that this belonging is important to the self-perception and identity (Pestana and Codina, 2019). Leaders in birding are therefore assumed to be birders themselves (in-group), but also to bring the group forward, and being one of their best representatives. Thus, it is assumed that these leaders should stand out from the rest of the group in birding specialization measures, such as in the number of bird species the leader is able to identify, and in his/her behavior related to birding. Therefore, the birding specialization framework can be applied in assessing the predictors of leadership in birdwatching.

Leadership in birding requires the organization of field trips, but also includes instructing people about birds and their environment as well as to motivate them for data collection. This requires skills and knowledge beyond the simple organization of the events. Leadership in birding has been rarely addressed although in nature conservation, many people volunteer in field trips. For example, the German NABU organization, which arose primarily from bird conservation, and then turned into a nature conservation organization has 820,000 members in 2,000 local chapters throughout Germany (NABU, 2021), and nearly all chapter leads some bird walks or field trips. Therefore, it is interesting to analyze predictors of leadership in birding. Some studies haven carried out previously, but only with few details and in North America. For example, more experienced birders are assumed to be more involved in wildlife conservation (Kellert, 1985) and in leadership roles (McFarlane and Boxall, 1996). McFarlane and Boxall (1996) showed that about 55% of the advanced birders led bird walks and/or gave presentations. The percentage of leading such activities increased from the novice to the advanced birder. This follows the pattern of longitudinal changes in recreation specialization in general (Bryan, 1977). Lee and Scott (2006) found that recreation specialization, with the four dimensions behavior, knowledge, personal, and behavioral commitment influenced the decision to obtain leadership roles. This leads to the importance of recreation specialization as an important aspect of birdwatching.

Birding Specialization and Serious Leisure

Different concepts have been applied in the study of serious leisure in its wider sense. One theory is based on Stebbins's (2017) definition of serious leisure, another conceptualization is based on recreation specialization (Bryan, 1977). Serious leisure is based on the following aspects (Stebbins, 2017): People immersed in a serious leisure activity develop a unique *ethos* on becoming involved, obtain lasting benefits (e.g., self-fulfillment), show perseverance, invest personal effort, and manage their leisure activity similar like a professional career, and, lastly, show a strong identification with the leisure activity (Codina et al., 2017). These aspects are all related to the hobby of birding. Concerning recreation specialization theory, this has been applied first to outdoor recreationists (angling, hunting, birding; Bryan, 1977). The essence of specialization theory is that outdoor recreation participants can be placed on a continuum from general interest and low involvement to specialized interest and high involvement (Bryan, 2000). Bryan (1977, 2000) further stated that the level of specialization is related to distinctive behaviors that are measured with commitment in time and money (e.g., replacement costs of the equipment, birdwatching tours, time spent birding, etc.), but also with personal and behavioral commitment. Both concepts are partly congruent but there are still many obstacles before these two could be unified (Scott, 2012). Both perspectives provide valuable insight into the complex forms of leisure activity. Scott (2012) has identified four important contributions of the specialization framework that helped to understand leisure phenomena: "there is *diversity* among participants involved in the *same leisure activity*, the number of specialized (or serious) participants can be quantified, there are gradations of seriousness, and there are practical applications of understanding that participants vary along a specialization continuum." (Scott, 2012, p. 370). From a more measurement-oriented perspective, serious leisure and recreation specialization overlap in the psychological dimensions, while recreation specialization differs in behavior and skill/knowledge, which is measured differently from the serious leisure concept. Items from the serious leisure concept can be easily adapted to other leisure activities because they are generic, which is a real benefit of the concept, while items from the specialization framework must be refined and adapted for each activity [e.g., compare items about the number of bird species a person knows (birdwatcher) with the number of fish one caught (angler)].

Here, in this study, the concept of recreation specialization is applied and preferred over the serious leisure approach, because it is more widely used and accepted in birding research. Further, it fits the leisure activity of birdwatching better (see, e.g., Scott, 2012). Lee and Scott (2013) further showed that serious leisure might be the overarching term for the facets of recreation specialization and serious leisure, and they concluded that both conceptual approaches may measure the same construct and could be applied together. Tsaur and Liang (2008) similarly showed an interrelationship between both concepts. In general, the specialization framework applies more questions related to real behavior, like number of field trips, knowledge about species (how many birds you can identify) and others, which makes the specialization measure more specialized and the serious leisure construct more general, but also applicable to other leisure activities (e.g., sports or music).

Birding specialization is a multidimensional construct (Lee and Scott, 2004), although it is sometimes simplified, and birders are then classified into three or four groups, e.g., as casual, novice, intermediate, and advanced birdwatchers (Scott et al., 2005). Following Lee and Scott (2004), the dimensions related to birding are four-fold. First, skill and knowledge are considered as one important part of birding specialization. More knowledge is related to a higher specialization score. Second, behavior measures the activities, such as birdwatching trips or days spent in the field, as well as equipment costs. Two dimensions are considered with behavioral and personal commitment, i.e., to what extent people are committed to birding, and how important this leisure activity is for their lives (Lee and Scott, 2004).

Some other lines of research followed the involvement approach to explain sustained interest in a leisure activity. In this respect, involvement reflects the degree to which people devote themselves to an activity (Kyle et al., 2007). This construct is also multi-dimensional and includes different dimensions, such as centrality to lifestyle, attraction (of a given leisure activity) and social bonding (Kyle et al., 2007). This analysis is based primarily on the recreation specialization construct outlined above, because skill/knowledge and behavior seemed to be more relevant to leadership roles, compared to the psychological aspects of centrality to lifestyle and attraction. However, as leadership is a social role, the social bonding scale of the involvement measure was also included.

The benefit of the more complex, multidimensional measure of birding specialization used in this study is that differences among the dimensions in birding can be assessed separately which gains more insight into the differences between leaders and non-leaders. In addition, using the social bonding scale helps to assess the social dimension.

MATERIALS AND METHODS

Survey and Participants

We collected data via the Online Research Tool SoSciSurvey in 2020. Participants were informed on the first webpage about the purpose of the study. After the information, participants had to actively click on "yes" to give their informed consent and to start with the study. Participants could stop and leave the study at any time without any negative consequences. One aim was to study a broad range of birdwatchers from novices to advanced birders. Therefore, the study did not focus on only one sampling method but to recruit participants via many channels, e.g., using announcements on the webpages of large bird and nature-related organizations, like naturgucker.de, nabu.de, do-g.de, and club300.de. Mailing list were used from some organizations (Naturgucker.de). All regional chapters of scientific ornithological unions, societies and clubs were asked for participation by using postings on their websites or by distribution of the link on their mailing lists. In addition, Facebook groups with a relation to birdwatching were used to post an information about the study. Finally, an advertisement was published in a printed birdwatching journal. This procedure covered a wide variation of birdwatchers of different organizations in German speaking countries (Germany, Austria, and Switzerland), from people preferring backyard birdwatching, to highly specialized birders and (semi-) professionals.

Demographic Variables

Age, gender, and age of birding initiation were asked for, as well as the highest degree. The degree was later recoded dichotomously into having received a university degree (bachelor, master, and diploma, etc.) or not.

Birding Specialization Measurement

Birding specialization was measured with an array of previously published instruments (see Randler, 2021a). The birding specialization questionnaire is an instrument that relates the four constructs skill/knowledge, behavior, personal, and behavioral commitment as related dimensions within a second-order factor structure (Lee and Scott, 2004).

Skill and Knowledge

Different measures are used to form the skill/knowledge scale. This included a self-report of the number of species a person is able to identify without a field guide by appearance, and by song without a field guide (Lee and Scott, 2004). Participants assessed their knowledge on a scale form 1 (novice) to 5 (expert) adapted from Lee and Scott (2004), but transformed to a five-point Likert scale. This scale contained open-ended questions (number of species being able to be identified by sonag and appearance). These open-ended questions were z-transformed prior to analysis. This was done because the range was from 0 up to 1,000 different species. Cronbach's α of the skill/competence scale was 0.85.

Behavior

This scale is based on self-reported real behavior, measured with six items. Behavior comprised questions about the number of birding trips taken last year (at least 2 km away from home; McFarlane and Boxall, 1996; Lee and Scott, 2004), number of days spent for birding last year (Lee and Scott, 2004), number of bird species on a lifelist (Tsaur and Liang, 2008), number of bird books owned (McFarlane, 1994), replacement value of the total equipment (Tsaur and Liang, 2008) and number of species on a national list (Randler et al., 2021). Open-ended questions were z-transformed prior to analysis. Cronbach's α of the behavior scale was 0.80.

Personal Commitment

Personal commitment was measured with three questions: "Other leisure activities don't interest me as much as birding." (Kim et al., 1997; Lee and Scott, 2004; Moore et al., 2008); "I would rather go birding than do anything else." (Moore et al., 2008; Lee and Scott, 2013) and "Others would probably say that I spend too much time birding." (Moore et al., 2008; Lee and Scott, 2013). All items were measured on a five-point Likert scale. Cronbach's α of the personal commitment scale was 0.76.

Behavioral Commitment

This scale refers to psychological aspects of behavioral commitment. Three items were used on a five-point Likert scale. "If I couldn't go birding, I am not sure what I would do." (Lee and Scott, 2004; Moore et al., 2008); "If I stopped birding, I would probably lose touch with a lot of my friends." (Moore et al., 2008; Lee and Scott, 2013) and "Because of birding, I don't have time to spend participating in other leisure activities." (Moore et al., 2008; Lee and Scott, 2013). Cronbach's α of the behavioral commitment scale was 0.72.

Social Bonding Measurement

Involvement in birding was based on the social dimension of the modified involvement scale (Kyle et al., 2007). Three items each measured "social bonding" (Cronbach's α = 0.79). These items were Likert scale from 1 = fully disagree to 5 = fully agree. Items were "I enjoy discussing birding with my friends," "Participating in birdwatching provides me with an opportunity to be with friends," and "Most of my friends are in some way connected with birding."

Leadership Questions

Leadership items were taken from McFarlane and Boxall (1996) and Lee and Scott (2006) and comprised two open questions: "How often during the last 5 years did you lead organized bird walks or field trips?" and "How often during the last 5 years have you given presentations about birds or birdwatching?". As the original questions of Lee and Scott (2006) were dichotomous, we additionally coded a dichotomous variable out of these data with 0 = people that neither led walks or gave talks, and 1 = people that gave at least one talk or led one bird walk.

TABLE 1 | Number of participants that took over leadership in field trips or presentations about birds.

		Presentation		Total
		No	Yes	
Field trips	No	1,917	146	2,063
	Yes	320	525	845
Total		2,237	671	2,908

TABLE 2 | Model fit values for leadership roles.

	−2 log-likelihood	χ^2	Cox and Snell	Nagelkerke's R^2
Leadership	2452.4	1267.9	0.355	0.490
Lectures	2151.1	983.6	0.288	0.436
Field trips	2381.8	1114.3	0.319	0.456

Statistical Analysis

The statistical program SPSS 26 was used for calculations. To assess nominal categories, a chi-square test was used with Cramer's phi to look for relationships. To correlate the number of field trips with the number of lectures, Spearman rho rank correlation was applied. Finally, to test all independent variables and their influence simultaneously, a binary logistic regression was applied. The sample sizes for the analysis differ for some reasons. First, for the binary logistic regression, outliers were removed, while in the chi-square test these data could be retained. For the correlation between field trips and number of lectures, all participants that gave neither a lecture nor led a field trip where ignored. To make the relative influence of the predictor variables comparable, a standardized measure of effect sizes was calculated. This measure was based on Menard's (1995) approach to obtaining fully standardized regression coefficients. These coefficients are interpreted as the predicted change in logits in standard deviation units per standard deviation unit increase on predictor k (Menard, 2004). The calculations were made with an excel sheet provided by Mike Crowson.[1]

RESULTS

From the initial 2,992, some questionnaires could not be used because people stopped during the questionnaire. Non-binary participants and people that preferred not to answer their gender were excluded because of the low sample size. For this current analysis, 2,908 full datasets were available. 1,518 participants were men, 1,390 were women (mean age: 47.7 ± 15.5; range: 18–88 years). Mean years of birding were on average 24.5 ± 19.1 (range: 0–79 years). 845 persons lead at least one field trip, and 671 gave one lecture; in the combination 991 took over at least one of the two leadership roles (**Table 1**). Mean number of field trips led during the last 5 years was 13.43 ± 14.86 (median: 6), and mean number of presentations given was 8.21 ± 11.13 (median: 4). The range was between 1 and 50, only participants that gave at least one presentation or led one field trip have been included (**Table 1**).

People most likely support both roles. Persons that gave presentations usually also led field trips (Phi = 0.593, $p < 0.001$). A correlation between the number of field trips and number of presentations was significant ($r_s = 0.502$, $p < 0.001$, $n = 525$), suggesting that people that give more presentations also lead more field trips. However, there are still people that preferred leading field trips but not giving presentations and vice versa (**Table 1**). Men more than women took over leadership roles ($\chi^2 = 214.96$ after continuity correction, $p < 0.001$, df = 1).

To address the influence of the predictor variables simultaneously, a binary logistic regression was used. For the binary logistic regression, outliers have been removed with a standardized residual higher than 5 or lower than −5. The variance inflation factors (VIF) were below 3; and the condition index was below 20. **Table 2** summarizes the model characteristics. Three full models were calculated, addressing the leadership role in general by combining trip leading and lecturing, and by separating both activities because there seem to be differences between the two. The effect sizes of the full models were reasonably high when using Nagelkerke's *R*-squared as a pseudo-measure of effect size.

In all three models, age played a significant role, with higher age being related to less leadership (**Table 3**). Gender was also significant with men taking over leadership roles more often. Graduation was not significant in the combined dataset and in leading field trips. However, concerning lecturing, a formal university degree was related to a higher probability of giving lectures about birds. Years of birdwatching were not significant. Social relatedness in the involvement scales was related to being a leader, also birding skill/competence as well as self-report behavior of birding were significant predictors for leadership roles. The commitment scales, both behavioral and psychological commitment were no significant predictors in the model. Skill/knowledge and social bonding had the highest effect (**Table 3**).

The strongest influence as measured by effect sizes (**Table 2**) was skill/knowledge in all three models, followed by social bonding and behavior. University degree was a less important predictor. Also, the effect sizes of the psychological commitment scales (personal and behavioral commitment) were low.

DISCUSSION

This study analyzed predictors of leadership in birdwatching. The correlation between field trips and presentations is interesting, suggesting that leadership in birding is not dependent on a specific activity and most leaders accept both roles. However, in some cases, people led only field trips or gave only lectures. This is interesting and probably related to the university degree. Giving a lecture seems to be a more "academic" activity compared to leading a field trip because the university degree was unrelated to the probability of leading field trips but related to lecturing. This has an encouraging implication because it shows that for field trips in birding, people do not necessarily need an academic

[1] https://www.youtube.com/watch?v=W8ktaSKVCL0

TABLE 3 | Predictors of leadership in birding.

	Coefficient B	Standard error	Wald statistics	*P*	Exp(B)	*b* (M)
(A) Leadership total						
Age	−0.020	0.004	19.844	<0.001	0.980	−0.097
Gender	−0.257	0.110	5.393	0.020	0.774	−0.040
University degree	0.041	0.105	0.155	0.694	1.042	0.006
Years of birding experience	−0.003	0.004	0.845	0.358	0.997	−0.018
Social bonding	0.723	0.076	89.722	<0.001	2.062	0.194
Skill/knowledge	1.452	0.129	127.024	<0.001	4.272	0.390
Behavior	0.624	0.132	22.239	<0.001	1.867	0.137
Personal commitment	−0.127	0.081	2.440	0.118	0.881	−0.037
Behavioral commitment	0.031	0.114	0.074	0.785	1.032	0.007
Constant	−0.794	0.328	5.876	0.015	0.452	
(B) Lectures						
Age	−0.024	0.005	21.730	<0.001	0.976	−0.130
Gender	−0.342	0.125	7.454	0.006	0.710	−0.060
University degree	0.306	0.116	6.977	0.008	1.358	0.053
Years of birding experience	0.000	0.004	0.000	0.988	1.000	0.000
Social bonding	0.626	0.081	60.058	<0.001	1.870	0.188
Skill/knowledge	0.966	0.115	70.757	<0.001	2.627	0.290
Behavior	0.634	0.127	24.968	<0.001	1.886	0.155
Personal commitment	−0.156	0.087	3.230	0.072	0.856	−0.051
Behavioral commitment	0.157	0.118	1.755	0.185	1.170	0.038
Constant	−1.463	0.355	16.988	<0.001	0.232	
(C) Field trips						
Age	−0.020	0.005	17.967	<0.001	0.981	−0.104
Gender	−0.272	0.115	5.627	0.018	0.762	−0.046
University degree	−0.034	0.107	0.101	0.750	0.966	−0.006
Years of birding experience	0.000	0.004	0.014	0.907	1.000	−0.003
Social bonding	0.653	0.077	72.480	<0.001	1.922	0.191
Skill/knowledge	1.273	0.121	110.501	<0.001	3.570	0.372
Behavior	0.514	0.127	16.386	<0.001	1.672	0.123
Personal commitment	−0.083	0.082	1.031	0.310	0.920	−0.027
Behavioral commitment	0.053	0.114	0.220	0.639	1.055	0.013
Constant	−1.164	0.333	12.226	<0.001	0.312	

Results of the binary logistic regressions. (A) Leadership total (including field trips and lectures). (B) People giving lectures. (C) People leading field trips. The standardized coefficients are in the last column [b (M)] and allow a comparison of the importance of the predictors.

degree, an aspect that is important for diversity in leadership and for role models of non-academics. Perhaps people preferring lecturing over a field trip might be afraid of the challenging nature of field trips because birds are unpredictable and move, so that species might appear that are unknown to the leader. Also, the participants can react more interactive during a field trip, while in presentations and lectures, one has more control about the situation. This might somehow be similar to biology teachers, usually with an academic degree, that prefer lecturing over field trips because of their inexperience and the unpredictability of the environment (Ateşkan and Lane, 2016).

Years of birdwatching was not significantly related to the probability of being a leader. This is an encouraging result because it shows that people may become leaders more quickly and do not need decades of experience before giving a talk or leading a field trip. This might also contribute to diversity when younger people take over such leadership roles.

However, an important predictor of leadership were the specialization measures, skill/knowledge and behavior. Skill knowledge was the predictor with the highest effect size (**Table 3**). People with a higher bird knowledge were more likely to be a leader in birding, which is a trivial result because a basic knowledge of birds should be available before someone starts leading trips or giving lectures. Interestingly, the behavior component also contributed to the models. Thus, leaders in birding also live what they proclaim; they are avid birders themselves and spent time outside birdwatching when they do not lead excursions. This is an important aspect because, again, this behavior helps in developing a leader to a kind of role model. Similarly, to McFarlane and Boxall (1996) this current study showed that specialization was a better indicator of participation in conservation activities than socioeconomic variables. The psychological and behavioral commitment scales from the birding specialization construct, however, were unrelated to the leadership role. Using the multi-dimensional model of specialization helped to entangle these differences between the dimensions and is an improvement over the study of McFarlane and Boxall (1996) who used a classification into four birder groups. Lee and Scott (2006) used a similar conceptualization of birding specialization and found a significant influence of skill/competence, behavior, and behavioral commitment on leadership. In common with their study, psychological commitment was not significant in both. However, behavioral commitment received significance. It can only be speculated about this result. For example, their measurement of commitment was collated from two items, and in this study, it was based on three. Further, the sample size is higher compared to the study of Lee and Scott (2006; $N = 642$). Next, the studies were carried out on different continents, are more than one decade apart, and finally, the previous study was conducted with members of the American Birding Association, while this one covered a wider range of birdwatchers.

As addition to the previous studies, the social bonding scale of the involvement construct (Kyle et al., 2007) was applied, following the hypothesis that leading is a somewhat social aspect. This could be confirmed in the current analyses. This is another important aspect. Social bonding from a leisure point of view seems necessary to become a leader in birding. This scale is especially tied to sociality in the given leisure activity and not to sociality in general. Here, new venues of research should look for associations in personality, especially for the agreeableness component of the Big Five (Randler et al., 2017). Additionally, it might be interesting whether aspects of the "dark side" of personality, such as narcissism are related to leadership in leisure organization in a similar way as they are in business companies (Judge et al., 2009).

Another important aspect not considered in this study is identity, as it is related to both, the establishing of a serious leisure activity, where this activity forms a substantial part of the identity (Codina et al., 2017; Stebbins, 2017) but also with respect to leadership. In leadership theories, especially in the social categorization/social identity of leadership (Haslam et al., 2011; Reicher et al., 2018; Turner and Chacon-Rivera, 2019; Pestana and Codina, 2020), identity plays a central role because the leader is representative for the group and its best representative.

Men more than women engaged in leadership roles. At least previously, women encountered far more constraints to leisure than do males (Henderson and Hickerson, 2007; Lee et al., 2015). This might be explained with the persistence of gender role stereotypes but should change in the future because of gender role transitions. As an alternative interpretation, being leader in leisure needs self-esteem, and there is a significant gender gap, with males consistently reporting higher self-esteem than females (Bleidorn et al., 2016). These aspects deserve future investigation because female mentors are beneficial since they positively influence career success in women (Propst and Koesler, 1998). Leaders in nature conservation and in CS projects also serve as possible role model or as mentors, with mentors being involved in caring for their protégé – which is not necessary in role models (Propst and Koesler, 1998). In this case, women as role models and/or mentors are important for educating the next generation of citizen scientists.

From a methodological viewpoint, concerning self-report measurements in questionnaires, one point should be made about the validity. Numerous studies have addressed the factor structure of the birding specialization questionnaires and the measurement model used here seems well established (Lee and Scott, 2004). Furthermore, Randler and Heil (2021) showed that people who assessed their bird knowledge higher in the questionnaire similarly performed better in a subsequent cognitive test where they had to identify different bird species ($r = 0.7$). This adds to the quality of the questionnaire.

Limitations

One limitation can be from the view of the theoretical underpinning because two approaches were used to assess serious involvement in a leisure activity (Scott, 2012). As Lee and Scott (2013) showed, the concept of recreation specialization and of serious leisure may measure the same construct and could be united somehow – although not many followers did really perform this – it might be an interesting idea for future studies to include both approaches into the study of leadership in birding. Further studies should also re-examine the relationship between the measures of recreation specialization and serious leisure. Nevertheless, skill/knowledge provided the highest effect size in all three models, suggesting that choosing the questionnaire focusing on recreation specialization, which contains exactly this measure, seemed the right choice.

This study did not cover the full side of the leadership construct but focused mainly on giving lectures and leading bird walks. However, this is still the major activity of leaders in birding. Future studies should address other roles of leaders as well as characteristics of successful leaderships. Other roles important in outdoor recreation leaders also include motivating the participants, encouraging them, empower volunteers and enable learning rather than distracting people from this activity (Ford and Blanchard, 1993; Benevone et al., 2020). A special focus may lie on transformational leadership, which concerns leaders who are highly inspiring and motivating for followers, helping them to meet higher performance targets (Almas et al., 2020). For volunteers in CS projects, effective leaders are necessary, at best with sympathetic personality and a non-hierarchical approach (Loos et al., 2015). In general, suitable leadership may transformational leadership, although it can coexist with a diverse range of leadership models (Charles et al., 2020). However, such studies have not yet been carried in birding and would be a fruitful venue of research. Further studies may also focus on the identity and social categorization of the leadership construct with respect to birding.

CONCLUSION

As a conclusion, this study adds to characterize leaders in birding, but open questions still remain on different roles of leadership, personality and motivational aspects, as well as in increasing diversity of the leaders. As an implication, more diversity is needed because older men most often took leadership roles.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the author, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Social Science and Economic Faculty of the University of Tuebingen (Az A2.5.4.–113_aa). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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The Value of Citizen Science in Increasing Our Knowledge of Under-Sampled Biodiversity: An Overview of Public Documentation of Auchenorrhyncha and the *Hoppers of North Carolina*

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Due to the increasing popularity of websites specializing in nature documentation, there has been a surge in the number of people enthusiastic about observing and documenting nature over the past 2 decades. These citizen scientists are recording biodiversity on unprecedented temporal and spatial scales, rendering data of tremendous value to the scientific community. In this study, we investigate the role of citizen science in increasing knowledge of global biodiversity through the examination of notable contributions to the understanding of the insect suborder Auchenorrhyncha, also known as true hoppers, in North America. We have compiled a comprehensive summary of citizen science contributions—published and unpublished—to the understanding of hopper diversity, finding over fifty previously unpublished country and state records as well as dozens of undescribed and potentially undescribed species. We compare citizen science contributions to those published in the literature as well as specimen records in collections in the United States and Canada, illuminating the fact that the copious data afforded by citizen science contributions are underutilized. We also introduce the website *Hoppers of North Carolina*, a revolutionary new benchmark for tracking hopper diversity, disseminating knowledge from the literature, and incorporating citizen science. Finally, we provide a series of recommendations for both the entomological community and citizen science platforms on how best to approach, utilize, and increase the quality of sightings from the general public.

Keywords: environmental education, community research, BugGuide, iNaturalist, leafhopper, treehoppers, planthopper, spittlebug

INTRODUCTION

In the last 2 decades, a number of citizen science platforms have been developed, leading to an explosion in the amount of people enthusiastic about observing and documenting nature (Hand, 2010; Bonney et al., 2014; Cox et al., 2015; Cooper, 2016; Aristeidou et al., 2021). These citizen scientists are collectively and opportunistically recording biodiversity on unprecedented temporal and spatial scales (Boersch-Supan et al., 2019; Fink et al., 2020). Citizen science data has therefore been receiving heightened attention from the scientific community in recent years (Adler et al., 2020). One well-known example of citizen science is eBird, a community science database that enables birdwatchers from around the world to contribute observations of birds (Sullivan et al., 2009; Amano et al., 2016). This enormous, long-term, and continuously growing dataset of bird count data consists of nearly a billion observations (Neate-Clegg et al., 2020) and can allow scientists to perform robust studies such as assessing avian population trends (Clark, 2017; Walker and Taylor, 2017; Horns et al., 2018; Fink et al., 2020), monitoring bird migration (Fournier et al., 2017; Horton et al., 2018), and helping inform the conservation of threatened species (Sullivan et al., 2017; Robinson et al., 2018; Lees et al., 2021). Similar bird observation data has also been used to model the effects of climate change on future distributions of bird species (Abolafya et al., 2013). However, there is a big difference between documenting birds and harder to identify taxa such as arthropods; not only are birds fairly well-known and more charismatic to the general public in comparison to most arthropods, but birds are typically much less challenging to photograph and identify, therefore being fairly easy to document (by both sight and sound). Furthermore, research has shown that while documentation of birds by the public has significantly increased in recent years around the world, data accumulation for non-avian taxa has not similarly accelerated (Amano et al., 2016).

One taxonomic group that has benefited from citizen science contributions is Auchenorrhyncha, an incredibly diverse group of herbivorous insects commonly referred to as true hoppers (hereafter referred to as "hoppers"). In North America, these hoppers consist of spittlebugs (Aphrophoridae, Cercopidae and Clastopteridae), leafhoppers (Cicadellidae), treehoppers (Membracidae and Aetalionidae), and planthoppers (Fulgoroidea). Cicadas (Cicadidae)—excluded from this study—also belong to Auchenorrhyncha and, while not every cicada genus is easy to identify, this group tends to receive heightened attention and recognition due to their life cycles, size, and audible courtship calls (Deitz, 2008). The remainder of hoppers on the other hand (being mostly small and skittish) tend to go unnoticed in the public eye, with only the most economically significant species receiving attention. As a result, there is a significant lack of information for most hopper species including biogeography, host history, and disease vector status. To further complicate matters, hopper taxonomy can often be extremely complicated and fluid, with some genera going decades without much-needed revision and the validity of certain species in doubt. There are also various schools of thought towards hopper taxonomy which often leads to conflicting methods of classification (Takiya, 2007).

The number of hopper taxonomists in the United States and Canada has been steadily rising after a steep decline in the late 1980s (though the overall number of hopper specialists is still low), with emerging tools and academic programs having enabled a resurgence in the number of entomologists proficient in hopper studies within the past 2 decades (Dietrich, 2013). An often overlooked "tool" that has continually increased the understanding of hoppers is citizen science. With constant monitoring of global biodiversity by hundreds of thousands to millions of people (Bonney et al., 2014; Jarvis et al., 2015), an unprecedented amount of data is now readily accessible to researchers. While most museum collections worldwide have not yet been digitized, citizen science data is instantly available and denotes a new era of scientific accessibility.

In this study, we examine the value of citizen science websites and citizen scientists in helping increase our knowledge of under-studied and under-sampled taxonomic groups, specifically focusing on Auchenorrhynchan hoppers. We provide an overview of the contributions of records on the citizen science websites BugGuide and iNaturalist in furthering our understanding of the abundance and distribution of various hopper species and compare this data with collection and specimen records. We highlight previously published examples of how citizen science can lead to the identification of new state and country records, the monitoring of introduced species, and even the description of new taxa. Additionally, we introduce the *Hoppers of North Carolina* website (hereafter shortened to *Hopper Site*; https://auth1.dpr.ncparks.gov/bugs/index.php) as a case study for the scientific community. This site is an updated approach to citizen science and knowledge dissemination, combining various online contributions with the scientific approach (characteristic of the entomological field) in studying arthropod biodiversity. Finally, we suggest how we, as scientists, can interact with and train the younger generations of amateur naturalists in order to maximize the value and accuracy of citizen science-based information.

METHODS

Literature Review

In order to evaluate the contributions of citizen science to the published study of Auchenorrhyncha, we conducted a systematic search of peer-reviewed literature on hoppers published since 2004, the first year after BugGuide was officially launched (*BugGuide*, 2021), in both Web of Science and Google Scholar. We narrowed our search to North America (United States and Canada) and used search terms—separated by commas—related to citizen science, the four main taxonomic groups of hoppers, invasive species monitoring, and the description of new species (**Supplementary Table S1**). We then narrowed our focus to publications that noted new state or country records of described species or the description of new taxa that were discovered thanks to citizen science documentation.

BugGuide and iNaturalist

Citizen Science Background

BugGuide.net and iNaturalist.org are two popular websites for recording and hosting nature observations, especially in the United States. These sites are generally focused on public outreach and biological education, but they also have much to offer scientifically. The inexperienced observers, the most dedicated enthusiasts, and experts leading their respective fields all merge in the communities that these sites build. The two sites strongly utilize the work of volunteers and are both substantial achievements in the realm of citizen science, although there are key differences between them.

BugGuide is an interactive online field guide that focuses on arthropods north of Mexico. Users are required to upload a photograph, a date, and a location for each entry. A user may move their own entry throughout the taxonomic tree of the site, but only designated Contributing Editors and a select few other roles may move images uploaded to the site within the Guide, add taxa to the site, and make edits to the site taxa. Entries that are deemed of little use to the Guide are deleted after a notification in 30 days. This high level of curation allows the site to be more selective in its presentation and favor a high standard of data quality, but also limits user interaction, as only selected curators can make changes on the site. Contributing Editors may also edit "Info" pages, which enable users to view a curated informational wiki that presents information on identification, taxonomic history, host preferences, distribution, and the number of child taxa (more specific taxonomic units, i.e. the number of genera in a tribe or the number of species within a genus).

This is in contrast to the globally-oriented iNaturalist, which is an online social network and identification system for amateur naturalists that was established in 2008 (Seltzer, 2019). iNaturalist does not take the same field guide approach as BugGuide and instead is mainly based around the users, with minimal hierarchy beyond simple site moderation and taxonomic curation. The site globally covers all biota, as opposed to BugGuide's focus on North American arthropods. When a user uploads an observation, an AI (artificial intelligence) will suggest a possible identification. Once the observation is uploaded, any user may suggest a taxon identification which informs the "Community ID," a voting-based identification system where each vote holds equal weight (regardless of a user's administrative role). The authoritative editors on iNaturalist are Curators and Staff, who moderate the taxonomic and social sides of the site. Selecting a taxon in iNaturalist immediately presents users with a view of user-based statistics, as well as three graphs illustrating the seasonality, history, and observed life stages of observations of the taxon. There is also an interactive distributional map for the taxon, showing coordinate-based pinpoints for each observation. These distributional maps are based on Google Maps and are much more advanced and precise than the BugGuide distributional maps, which simply note which states or provinces a taxon occurs in.

Data and Statistics

Data from BugGuide were obtained (on May 11, 2021) through the (as of writing) beta website BugGuide 2.0, which allows users to see the number of observations within a taxon when the "Info" tab is selected. The number of entries for Auchenorrhycha was recorded with the number of Cicadoidea observations subtracted.

Data and statistics from iNaturalist were obtained (on May 11, 2021) by searching "Auchenorrhyncha" through the "Explore" page (also referred to as "Observation search"). The location field was left blank to obtain global results. Data for Cicadoidea were excluded through the use of an extension added to the end of the URL which excludes a specific taxon from the search: http://&without_taxon_id = (taxon_id). The numbers of observations, species, identifiers, and observers were recorded based on the results of the search. Then, iNaturalist data for observations in North America were obtained through the creation of a "Collection Project," which enables users to set certain parameters for a more specific search, including the addition and/or exclusion of multiple locations and taxa. Cicadoidea was again excluded from the search and the geographic range of the Collection Project was confined to the United States and Canada, excluding Hawaii and island territories.

Observation data on iNaturalist is divided among three categories: "Casual," "Needs ID," and "Research Grade." "Casual" observations are entries that lack associated images, dates, and/or locations—we have excluded such observations from all searches made for this study. "Needs ID" observations are entries that include all of the aforementioned metadata that a "Casual" observation would lack, but have only been identified to a taxon higher than species-level or have been identified to species by only one user. "Research Grade" observations are entries that include all required metadata and have been identified to species by two or more users without a dissenting identification or have a majority of identifications in agreement. For the purposes of this study, we used both "Research Grade" and "Needs ID" observations.

To compare citizen science records on BugGuide and iNaturalist with those in collections, we searched records for spittlebugs (Aphrophoridae, Cercopidae, *Clastoptera*), leafhoppers (Cicadellidae), treehoppers (Membracidae, *Aetalion*), and planthoppers (Acanaloniidae, Achilidae, Caliscelidae, Cixiidae, Delphacidae, Derbidae, Dictyopharidae, Flatidae, Fulgoridae, Issidae, Kinnaridae, Nogodinidae, Tropiduchidae) for the continental United States and Canada on the "Search Records" page of iDigBio.org, an online database of digitized collection-based specimen data (*iDigBio*, 2021). While iDigBio does not necessarily contain data from every collection in North America, it has fantastic reach and functions as the coordinating center for the national effort by collections to digitize their specimens (*iDigBio*, 2021), therefore serving as a great representation of collections across the region. We then summed these records to produce an overall number of collection records for hoppers in North America.

We also compiled a list of country records as well as state, provincial, or territory records of recently described hoppers in North America that were submitted by citizen scientists to either BugGuide or iNaturalist and have not yet appeared in the literature. Additionally, we compiled a list of known undescribed and potentially undescribed (consisting of "probably" and "possibly" undescribed taxa) hopper species that have been documented on these citizen science platforms. For this paper, a "known undescribed" hopper is one that has been confirmed by experts, either via specimen analysis, dissection, or genetic barcoding, to be an undescribed species that has yet to be formally described. A "probably undescribed" hopper is one that is most likely undescribed but we are unaware of there being any proper specimen analysis by an expert to confirm this. A "possibly undescribed" hopper is one that does not currently seem to match anything in the literature but we cannot completely rule out a poorly known species or an unknown color form of something described. For both lists, we noted which state or province these hoppers have been recorded in, the online source of the records, and the initial identifier of these records. We also noted which record entries have been confirmed via specimen analysis.

Hoppers of North Carolina

Website Background

In North Carolina, there is a significant focus on researching and documenting wildlife, particularly arthropods. The state has many resident entomologists, experienced field naturalists, and experts from both within and outside the state conducting research (NCBP, 2017). As a result, there is a great deal of information about arthropod taxa in the state and a growing focus on making this information available to the public online. A *Butterflies of North Carolina* website was created in 1994 (LeGrand and Howard, 2021), and then *Dragonflies and Damselflies of North Carolina* went online in 2010 (LeGrand et al., 2021). These original two online taxonomic databases for North Carolina disseminate knowledge of species distributions, natural and life history, identification, and conservation status to the public, serving as the authoritative sources for these two taxonomic groups in the state. These sites are open to the public, allowing any person to find a comprehensive list of the butterflies and odonates known to occur in each county, learn how to identify these species, and peruse a library of images taken in the state for each species. In the case of *Dragonflies and Damselflies of North Carolina*, the public can submit their own records and photographs directly to the database.

With this hybrid perspective in mind, the first author began in summer 2013 to develop a website to increase the overall knowledge of the spittlebugs, leafhoppers, treehoppers, and planthoppers found in North Carolina. The *Hopper Site* was developed through a partnership with the North Carolina State Parks System (Kittelberger and Howard, 2021). In May of 2017, the overall development of the *Hopper Site* was completed and the site was opened up to public use and record entry. The *Hopper Site* has three main functions: an online photographic field guide, records database, and citizen science platform (Kittelberger and Howard, 2021).

The *Hopper Site* is also a part of the North Carolina Biodiversity Project (NCBP), a private organization whose mission is to promote public interest in the state's native species and ecosystems and their conservation (NCBP, 2017). This organization, which works in partnership with the North Carolina Division of Parks and Recreation, is composed of taxonomic experts, conservation biologists, science educators, and others that have had a long history of studying particular taxonomic groups in North Carolina. The NCBP currently consists of twenty websites and checklists for various taxa and serves as the most complete online coverage of the biodiversity in North Carolina.

Data and Statistics

Information on the usage of the *Hopper Site* was obtained by the site administrator entering the records into a database table. All the records were then extracted into a CSV file, and the number of both contributors and different "observation types" were tabulated using back-end administrative tools accessible to the site administrator.

RESULTS

Value of Citizen Science in the Knowledge of Hoppers Based on Literature Review

In our search of the literature, we found 10 publications that listed noteworthy records of 17 species that are specified as being either documented by individual citizen scientists (1 species; McKamey and Sullivan-Beckers, 2019) or contributions made to online citizen science platforms in North America (BugGuide or *Hopper Site*; **Table 1**). We also located one publication (Leavengood et al., 2017) containing a noteworthy record that was found by a member of the public but

TABLE 1 | Noteworthy records of hopper species in North America that were mentioned in the literature as being documented by citizen scientists, either individually or on a citizen science website. U S A = United States of America, CAN = Canada; abbreviations are used for states. INT indicates an introduced/adventive species.

Scientific name	Record type	Literature source	Citizen science site(s) noted
Lepyronia angulifera Uhler, 1876	State record (GA, NC, NY, MI, VT)	Hamilton, 2012	BugGuide
Clastoptera octonotata Hamilton, 2015	New species (SC, NC)	Hamilton, 2015	BugGuide
Balclutha rubrostriata Melichar, 1903	Country record (USA)[INT]	Zahniser et al., 2010; Carlson et al., 2012	BugGuide
Erasmoneura atra Johnson, 1935	State record (NH)	Chandler and Hamilton, 2017	BugGuide
Eupteryx atropunctata Goeze, 1778	State record (NH)[INT]	Chandler and Hamilton, 2017	BugGuide
Eupteryx decemnotata Rey, 1891	State records (NC, NJ, NM, UT)[INT]	Ciafré and Barringer, 2017; Tasi and Lucky, 2020	BugGuide, Hoppers of NC
Empoasca kittelbergeri[a] Chandler and Hamilton, 2017	New species (NH)	Chandler and Hamilton, 2017	BugGuide
Empoasca murrayi[a] Chandler and Hamilton, 2017	New species (MA, NH)	Chandler and Hamilton, 2017	BugGuide
Hebata zanclus Hamilton and Langor, 1987	State record (VT)	Chandler and Hamilton, 2017	BugGuide
Hishimonus sellatus Uhler, 1896	Country record (USA)[INT]	Hamilton, 2011	BugGuide
Iassus lanio Linnaeus, 1761	Country record (CAN)[INT]	Hamilton, 2011; Carlson et al., 2012	BugGuide
Tremulicerus fulgidus Fabricius, 1775	Country record (USA)[INT]	Carlson et al., 2012	BugGuide
Macropsis infuscata Sahlberg, 1871	Country record (CAN)[INT]	Hamilton, 2011	BugGuide
Oncopsis flavicollis Linnaeus, 1761	Country record (CAN)[INT]	Hamilton, 2011	BugGuide
Pagaronia minor Anufriev, 1970	Country record (USA)[INT]	Hamilton, 2011	BugGuide
Hebetica sylviae McKamey and Sullivan-Beckers, 2019	New species (KY)	McKamey and Sullivan-Beckers, 2019	Other
Asarcopus palmarum Horváth 1921	State record (TX)[INT]	Leavengood et al., 2017[b]	BugGuide
Haplaxius ovatus Ball, 1933	State record (FL)	Wheeler and Wilson, 2014	BugGuide

[a]*These species are currently unplaced within the tribe Empoascini, as they were not treated in the latest revision of the tribe (Xu et al., 2021), which redefined its component genera.*
[b]*This publication was not found in our initial search of the literature, since it does not include any reference to citizen science, and instead was found when we were looking for information on the year this species was introduced in California.*
State abbreviations: FL = Florida, GA = Georgia, KY = Kentucky, MA = Massachusetts, MI = Michigan, NH = New Hampshire, NJ = New Jersey, NM = New Mexico, NY = New York, NC = North Carolina, SC = South Carolina, TX = Texas, UT = Utah, VT = Vermont.

which does not list the citizen science platform (BugGuide) to which this record was initially submitted (see **Table 1** for more details). Of these 18 species, seven appear to represent first country records and seven represent first state records, while four are recently described species (**Table 1**; Chandler and Hamilton, 2017; Hamilton, 2015; McKamey and Sullivan-Beckers, 2019), demonstrating the value of citizen science in helping detect the presence of undescribed species.

There is great potential for citizen science to function in a passive surveillance role of hoppers, with the identification by experts of individual arthropods that were photographed by someone else. This passive surveillance can be especially instrumental in helping detect recently introduced species in North America (Hamilton, 2011; Carlson et al., 2012). Several nonindigenous insects were first detected in the United States and/or Canada via submissions to BugGuide (Hamilton, 2011; Carlson et al., 2012), including seven hopper species (**Table 1**; Carlson et al., 2012; Hamilton, 2011; Zahniser et al., 2010). Likewise, passive surveillance by citizen scientists can help experts document and monitor the spread of these introduced and, in some cases, invasive species (**Table 1**; Carlson et al., 2012; Chandler and Hamilton, 2017; Ciafré and Barringer, 2017; Leavengood et al., 2017; Tasi and Lucky, 2020). On the other hand, misidentified species that would represent first records for North America can make their way into the literature (see *Protalebrella tertia* in Carlson et al., 2012). This misidentification of notable records could be problematic for what would be any introduced and potential pest species, underscoring the need for a high standard of vetting of species identifications on citizen science platforms.

Citizen science can also provide insight into adult-nymph associations, interspecies relationships, population growth and decline, host plant data, and previously undocumented or poorly known behaviors of hoppers (Hamilton, 2011). It has even been cited as helping shed light on potential taxonomic relationships between treehoppers and leafhoppers, with photographic contributions of nymphs of both taxa on BugGuide providing supportive evidence that treehoppers may be neotenous leafhoppers (Hamilton, 2012). With the explosion of digital photography helping increase the documentation of all aspects of the life stage of hoppers in high detail in a way that might not have been previously available in collection-based specimens (Hamilton, 2011), citizen science can therefore play a role in furthering our understanding of the evolutionary history and systematics of these bugs (Hamilton, 2011, 2012).

We were unable to find any hopper literature in our search that referenced citizen science contributions from iNaturalist from North America. Even though there are far more Auchenorrhyncha hopper sightings and contributors on iNaturalist compared to BugGuide (see Results, *BugGuide and iNaturalist*), this absence of iNaturalist from the literature is likely a result of the site being several years younger than BugGuide and only having shifted to its current platform layout within the last decade. Additionally, in contrast with BugGuide, iNaturalist tends to be less taxonomically focused, have significantly more uploads, and any user can provide an identification of equal weight to an expert. Because of this, the veracity of sightings—particularly of lesser-known taxa—can sometimes be weaker than that of BugGuide. Perhaps these characteristics have prevented contributions from citizen scientists on iNaturalist from being valued as much as those on BugGuide by North American Auchenorrhynchologists. The small number of references to citizen science sites in hopper publications may also be a result of the small number of Auchenorrhynchologists in the United States and Canada. With only a dozen or so leading hopper taxonomists in North America, many focusing on global taxonomic groups and the training of new entomologists, publications citing citizen science contributions may be sidelined.

BugGuide and iNaturalist

As of May 10, 2021, there have been 59,907 hopper records uploaded to BugGuide (**Figure 1**). In comparison, as of May 11, 2021, there have been 310,740 hopper observations (of 4,360 identified species) uploaded to iNaturalist by 53,635 users. 167,157 of those observations were located in North America (**Figure 1**), with 1,343 different species recorded. Globally, 10,043 users contributed identifications. Therefore, there are 227,064 records for hoppers from iNaturalist and BugGuide in continental North America. In comparison (**Supplementary Figure S1**), on iDigBio we found 23,499 collection records of spittlebugs, 212,098 of leafhoppers, 79,734 of treehoppers, and 78,176 of planthoppers, resulting in a total of 393,507 hopper specimens in collections across continental North America (**Figure 1**). As a result, citizen scientists on BugGuide and iNaturalist have documented in less than 2 decades a number of individual hoppers that is equivalent to approximately 58% of collection records, largely from the 20th century, in continental North America. Additionally, on iNaturalist there has been a clear annual exponential growth between 2009 and 2020 in not only the number of observations of hoppers in North America but also the number of contributors (**Figure 2**), with 16,131 contributors submitting 78,923 observations in 2020.

We found records of 24 taxa that represent noteworthy records of hoppers documented first by citizen scientists online that have not yet been published in the literature (**Table 2**). There are 20 taxa that are apparent first country records for either the United States or Canada, with the other four taxa consisting of notable state records, including of two recently described species (*Clastoptera octonotata* Hamilton, 2015; *Telamona stephani* Wallace, 2018; **Figures 3A,B**). Seven of these taxa are also introduced species that are very recent additions to the North American fauna within the last couple decades (*Acericerus ribauti, Curtara insularis, Eupteryx decemnotata, Eupteryx filicum, Tautoneura cf. polymitusa, Chloriona sicula* (**Figure 3F**)*, Issus coleoptratus*; **Table 2**). We also found five undescribed, four probably undescribed, and seven possibly undescribed taxa that have been documented by citizen scientists (**Supplementary Table S2**).

Hoppers of North Carolina Description

Online Photographic Field Guide

First and foremost, the *Hopper Site* functions as an online photographic field guide. The most notable feature of the site is its family photo gallery, an innovative approach to hopper identification that is designed to serve as a photographic key to species' identification—it is both informative and easy to navigate. The page has a list of all the families representing the hopper fauna found in North Carolina, with subfamilies used to help organize and divide the speciose and diverse Cicadellidae (leafhoppers). Four photographs represent each family or subfamily on this page, allowing for comparisons of these groups and serving as the first step for aiding any user of the site that is trying to narrow down the identification of a hopper.

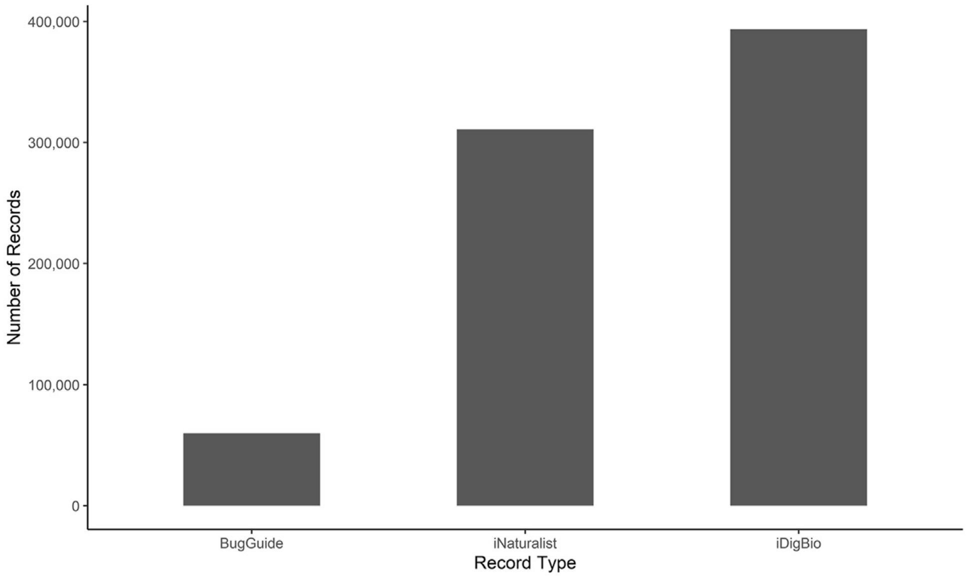

FIGURE 1 | The number of hopper records through May 11, 2021 from North America (United States and Canada) in BugGuide, iNaturalist, and digitized collections in iDigBio. There are 59,907 BugGuide records and 167,157 sightings from iNaturalist. In comparison, there are 393,507 specimens in digitized collections in iDigBio.

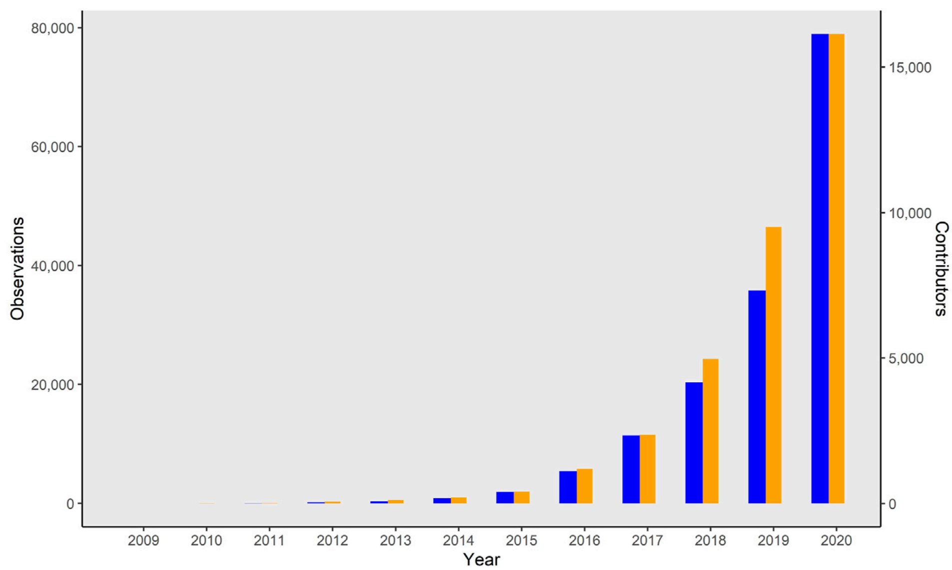

FIGURE 2 | Growth on iNaturalist in the number of hopper observations (blue) and the number of citizen science contributors (orange) in North America (continental United States and Canada) from 2009 through 2020.

Clicking on the family or subfamily link above a set of four photos leads to a new page that displays images for all the species in that particular taxonomic group. There are typically two to three images representing a species, depicting, when possible, images of both adult sexes and the nymphal life stage. This gallery view allows a user to quickly and easily compare images of species, particularly those that are similar and challenging to distinguish. Clicking on the scientific name of a hopper then redirects a user to the profile page for that species.

The profile page for a species mirrors that of a species' entry in a field guide and consists of six parts. At the top of the page are up to four diagnostic photos which, if important for a species' identification, can include views of the male subgenital plates or female pregenital sternite. As on the family photo gallery pages, the adult male and female as well as the nymph are pictured, if possible. Below the photos is a "Taxonomy" section, which can include the family, subfamily, tribe, and in some instances subgenus the species belongs to, as well as listing the taxonomic author that described the species. Following this is an "Identification" section, consisting

TABLE 2 | Known country records and notable state records (either recently described or adventive species) of Auchenorrhynchan hopper taxa in North America that were first documented by citizen scientists but have not yet been mentioned in the literature. USA = United States of America, CAN = Canada; abbreviations are used for states and provinces. INT indicates an introduced/adventive species, and an asterisk * indicates a record that was confirmed via specimen. "cf" is used to indicate a taxon that most resembles an already described species, but identification cannot be confirmed without a specimen. The initial identifier column lists the original expert source(s) that provided identification of the first record(s) of a particular taxon; the list of names for these abbreviated names can be found at the end of the table.

Scientific name	Record type	State or province	Citizen science source	Initial identifier
Aeneolamia albofasciata Lallemand, 1939	Country record (USA)	AZ	BugGuide*	VT
Aeneolamia contigua Walker, 1851	Country record (USA)	TX	iNaturalist, BugGuide	VT
Cephisus cf. brevipennis	Country record (USA)	TX	iNaturalist	VT
Clastoptera octonotata Hamilton, 2015	State records, new species	FL, AL, LA, TX	BugGuide	KK
Acericerus ribauti Nickel and Remane, 2002	Country record (USA)[INT]	NY, CT	BugGuide*	JK
Allygus mixtus Fabricius, 1794	Country record (CAN)[INT]	ON	iNaturalist	SH
Curtara insularis Caldwell, 1952	State records[INT]	OK, TX, LA, MS, AL, GA, NC, SC	BugGuide, Hoppers of NC, iNaturalist	JK, SH, KK
Dikrella scimitar Chandler and Hamilton, 2017	Country Record (CAN)	ON	iNaturalist	SH
Draeculacephala inscripta Van Duzee, 1915	Country Record (CAN)	ON	iNaturalist	KK
Egidemia cf. inflata	Country record (USA)	TX	iNaturalist	SH
Eupteryx decemnotata Rey, 1891	Country record (CAN)[INT], state records[INT]	BC; AL, GA, MA, MD, MO, OR, TX, VA, WA	BugGuide, iNaturalist	KK, SH
Eupteryx filicum[a] Newman, 1853	Country record (USA)[INT], province record[INT]	BC; WA, CA	iNaturalist, BugGuide	JK
Graphogonalia cf. evagorata	Country record (USA)	TX	BugGuide	CM
Neozygina veracruzensis Dietrich and Dmitriev, 2007	Country record (USA)	TX	BugGuide*	CD
Tautoneura cf. polymitusa	Country record (USA)[INT]	MO	iNaturalist	SH
Erechtia sp.	Country record (USA)	CA	iNaturalist	SM
Philya lowryi[b] Plummer, 1936	Country records (USA)	AZ, NM	BugGuide	AH*
Stictolobus borealis Caldwell, 1949	Country record (USA), State records	ON; IA, IN, OH, PA, TN, VA	BugGuide, iNaturalist	SH
Telamona stephani Wallace, 2018	State records, new species	FL, AL, CT, GA, MA, MO, NJ, NY, OH, RI, TN, WV	BugGuide, iNaturalist	KK, MW
Chloriona sicula Matsumura, 1910	Country records (CAN, USA)[INT]	ON, QC; MA, NY	BugGuide, iNaturalist	CB
Tarophagus colocasiae Matsumura, 1932	State record[INT]	LA	iNaturalist	CB
Anotia firebugia Bahder and Bartlett, 2020	Country record (USA)	TX	iNaturalist*	BB
Issus coleoptratus Fabricius, 1781	Country records (CAN) [INT]	BC	BugGuide*	JK
Melormenis cf. leucophaea	Country record (USA)	AZ	BugGuide	SH

[a]There are no known published records of this species in North America, but JK has informed the authors that he has a collected specimen from Vancouver, British Columbia.
[b]According to AH in a comment on BugGuide, there is a single specimen of this species in the Canadian National Collection that was collected from Arizona in 1998. However, this record is not noted in a comprehensive overview of the Nearctic Treehopper fauna (Deitz and Wallace, 2012). Therefore, we are including this record in this table.
State and Provincial abbreviations: AL = Alabama, AZ = Arizona, BC = British Columbia, CA = California, CT = Connecticut, FL = Florida, GA = Georgia, IA = Iowa, IN = Indiana, KY = Kentucky, LA = Louisiana, MA = Massachusetts, MD = Maryland, MI = Michigan, MO = Missouri, MS = Mississippi, NH = New Hampshire, NJ = New Jersey, NM = New Mexico, NY = New York, NC = North Carolina, OH = Ohio, OK = Oklahoma, ON = Ontario, OR = Oregon, PA = Pennsylvania, QC = Quebec, RI = Rhode Island, SC = South Carolina, TN = Tennessee, TX = Texas, UT = Utah, VA = Virginia, VT = Vermont, WA = Washington, WV = West Virginia.
Initial Identifiers: AH = Andy Hamilton; BB = Brian Bahder; CB = Charles Bartlett; CD = Chris Dietrich; CM = Chris Mallory; JK = Joel Kits; KK = Kyle Kittelberger; SH = Solomon Hendrix; SM = Stuart McKamey; VT = Vinton Thompson.

of a detailed description of how to identify the species, including when possible for both sexes and the nymph. Descriptions of the subgenital plates and pregenital sternite, morphometric information, and/or field marks distinguishing different subspecies are also included.

Next, there is a "Distribution in North Carolina" section that includes a state map, populated from county records with colors distinguishing the type of record (i.e., photographic record, visual sighting, external citizen science website source, or collection source). Clicking on a county will open a new tab with a list of each record for that county. Information about distribution, abundance, and seasonal occurrence follows the map, with seasonal occurrence also populated from submitted records. The fifth section is "Habitats and Life History," which describes which habitats the species can be found in, what plant species it is associated with, and any interesting behavior. The status of the species in the state (native or introduced) is also noted, and a comments section is included which is often used by the author to provide helpful information such as how to distinguish the hopper from similar species and clarifying any taxonomic issues that may confound identification. Finally, there is a "Species Photo Gallery" which includes every photo submitted to the site for that species. Links are sometimes scattered across the profile page leading the user to other sites with additional photographs of live or pinned specimens, taxonomic accounts, or publications that were consulted to write the profile.

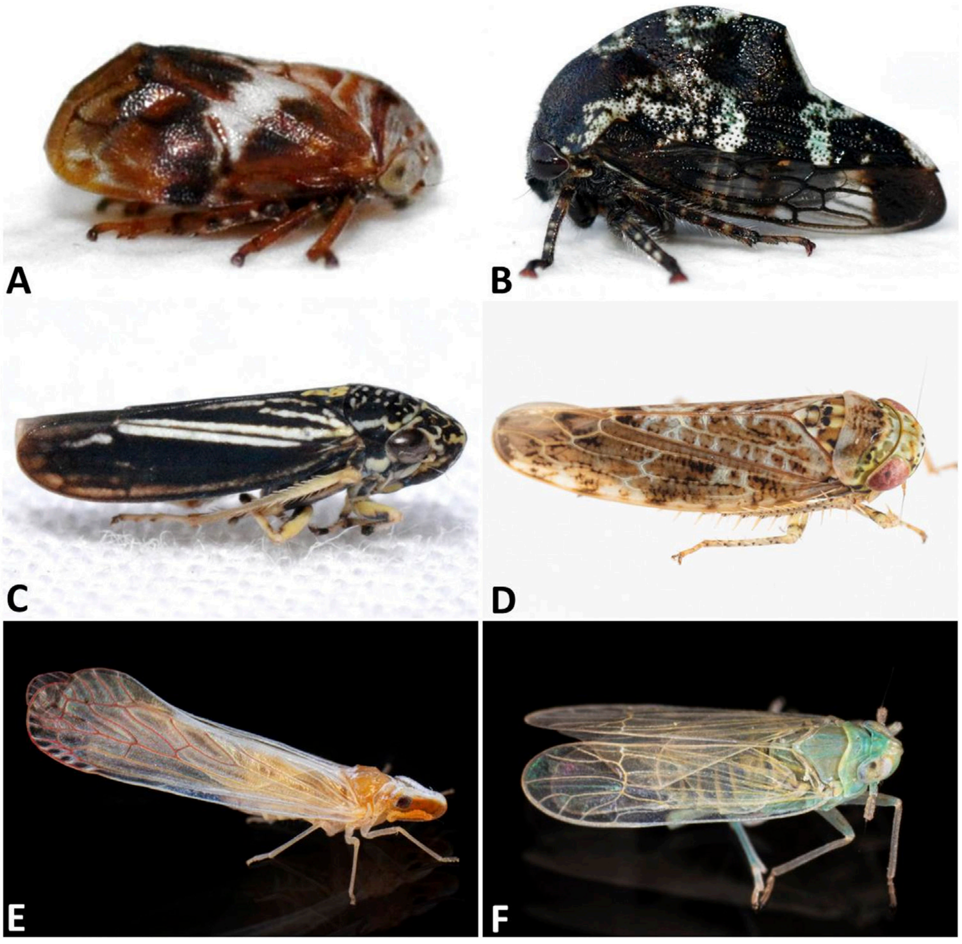

FIGURE 3 | Noteworthy hopper species from continental North America that are mentioned in this study. (**A**) *Clastoptera octonotata* Hamilton, 2015- a spittlebug that was recently described and documented based on citizen science contributions (**Table 1**); (**B**) *Telamona stephani* Wallace, 2018- a recently described treehopper with first state records documented by citizen scientists (**Table 1**); (**C**) *Graphocephala hieroglyphica* Say, 1830- a leafhopper that was first detected in North Carolina by citizen scientists (**Supplementary Table S3**); (**D**) *Allygus mixtus* Fabricius, 1794- an introduced leafhopper species that was first documented in Canada and rediscovered in Massachusetts by citizen scientists (**Supplementary Table S3**); (**E**) *Shellenius schellenbergii* Kirby, 1821- this infrequently encountered planthopper was first detected in North Carolina by citizen scientists (**Suppplementary Table S3**); (**F**) *Chloriona sicula* Matsumura, 1910- an introduced planthopper that was first detected in the United States and Canada by citizen scientists (**Table 2**). All hoppers photographed by Kyle Kittelberger (**A–C**) or Solomon Hendrix (**D–F**).

Records Database

The records in the *Hopper Site* database come from several main sources. Much of the data entered into the site originated from field surveys carried out by the first author visiting parks and other protected areas across the state between 2010 and 2020. The first author kept very detailed accounts of any diurnal or nocturnal surveys, recording the species found, numbers of each taxon present, habitat information, and, if applicable, host plant. The first author also submitted photographs and specimen information, such as sex and measurements, to go along with any of these submissions.

A large portion of the remaining records on the site originated from collections and the literature. The first author spent several months combing through pinned specimens in the NC State Insect Museum and incorporated all of these records into the *Hopper Site*. Other records were provided from two smaller in-state collections, from the Schiele Museum and lepidopterist J. B. Sullivan. The website iDigBio was also used to enter hoppers collected in-state but housed in facilities outside North Carolina. Other records were incorporated from various publications, particularly several comprehensive county-based checklists of treehoppers.

However, in an effort to have the records database be truly comprehensive and representative of the knowledge of species' abundances and distributions in the state, and to take advantage of all types of documentation and knowledge contributions, the *Hopper Site* does not solely rely on personal and collection records. North Carolina State Parks (NC DPR) has its own state-wide inventory platform, the Natural Resources Inventory database (NRID), which NC DPR personnel use to submit records of biodiversity across state parks and natural areas. NRID is fully linked with the *Hopper Site* so that these records are automatically synced with the site. Perhaps most noteworthy, however, is the citizen science component of the website that helps increase coverage and fill in gaps in species' distribution.

Incorporating Citizen Science

Members of the public can contribute their own sightings to the *Hopper Site* by submitting records on the "Enter Record" page. There is a series of required information fields for the metadata of a record, such as location, date, email for correspondence, and the option to include other information such as plant associate and time of day. People are also required to upload at least one image to corroborate their sighting. If someone is unable to identify a hopper they have photographed, they can choose an unidentified option. These unidentified records can then be identified, if possible, by the site author, and the author will correspond with the contributor via their included email about these sightings.

These public records, along with those from NRID, are immediately quarantined to a section of the site that is only accessible to the administrators. These records are therefore not assimilated into the records database until being vetted by the site author. This approach helps filter records and prevent erroneous identifications from the public from being incorporated into the website. If an entry cannot be correctly identified to species level, the record is moved to a purgatory section of the site where it remains hidden from the public and does not factor into the website's database.

Furthermore, records from BugGuide and iNaturalist are added to the database by the site author on a daily basis. While these websites can have issues when it comes to the accuracy of some species' identifications and taxonomy, these challenges do not prevent these submissions to these sites from being valuable and informative. The site author vets any record from these two citizen science websites before entering them directly into the *Hopper Site*, noting the source of each sighting during record entry. With the incorporation of records from BugGuide and iNaturalist, all major sources of hopper records have been accounted for, ensuring that the *Hopper Site* database is comprehensive and reflective of what has been recorded in the state.

Other Features

Other features of the *Hopper Site* include pages describing frequently used Auchenorrhyncha anatomical terms and a complete checklist of the species currently known from North Carolina, with abundances in each of the three state regions noted. A page devoted to hopper genitalia includes images of the ventral view of species in challenging to identify groups, such as *Cedusa* spp. and Membracidae, where knowing the sex of an individual can be imperative to determining a species' identification. There is also a page describing how to search for and find hoppers during diurnal or nocturnal hours and the kinds of equipment that the authors recommend, along with a detailed account of approaches to photographing individual hoppers.

Hopper Site Statistics

As of May 12, 2021, there have been 18,256 records entered into the website. There are 836 profile pages for hoppers in North Carolina, a number that continues to grow with the addition of more records. In terms of citizen science contributions, 436 of the 18,256 records originated from BugGuide, whereas 4,287 records came from iNaturalist, resulting in 26% of the records coming directly from these two platforms (**Figure 4**). Additionally, there have been at least 104 members of the public that have collectively contributed 3,775 hopper sightings (21% of records) to the database. The most prolific contributor has submitted 1,171 records, followed by someone at 523 records and five other citizen scientists contributing around 100–300 records individually. Together, citizen science accounts for 8,498 records, 47% of all site records. In comparison to these citizen science records, 5,806 records come from collections and the literature (**Figure 4**).

Of the 836 profile pages, 796 represent species reported from within the state. There are 34 profiles that consist of genus-level entries or species complexes for taxa that contain species that are extremely challenging to distinguish or impossible to identify from a picture alone, requiring additional angles, measurements, knowledge of the sex, and/or dissection. These 34 profiles therefore serve as umbrella pages for unidentifiable records. Additionally, there are six profile pages for currently known undescribed species reported from the state. The county with the highest number of submitted records is Wake County (35°47′N 78°39′W), currently at 458 species and umbrella pages, followed by Mecklenburg (260 profile pages; 35°15′N 80°50′W) and Buncombe (234 profile pages; 35°37′N 82°32′W).

We counted 53 first state records of hopper species in North Carolina (**Supplementary Table S3**) that were initially documented by citizen scientists on BugGuide (6 species), iNaturalist (27), or contributors uploading directly to the *Hopper Site* (21). There have also been five undescribed or potentially undescribed species first discovered in the state by contributors to the site (**SupplementaryTable S3**).

Citizen Science Recommendations

We first and foremost encourage researchers to become active in engaging with citizen scientists on various platforms. In the experience of KDK and SVH, engaging with the public helps foster their excitement to continue photographing, for example, hoppers, and we have observed many users choosing to photograph hoppers as a hobby. As the lead moderators of hoppers on BugGuide and iNaturalist over the last 7 years, KDK and SVH have developed numerous correspondences with BugGuide and iNaturalist contributors across North America and even beyond, with these users tagging or messaging us about their hopper sightings and asking for assistance with identifications.

Engaging with citizen scientists can also be instrumental to the accuracy of identifications and therefore the usability of these sightings in research (Wilson et al., 2020). We have the ability to easily correct or agree with identifications, particularly on iNaturalist, and taking time to vet records can make a significant difference in increasing the value of the data (Wilson et al., 2020). Users tend to be very receptive to having their identifications corrected, with many inquiring about what is needed to identify a hopper to species level. As

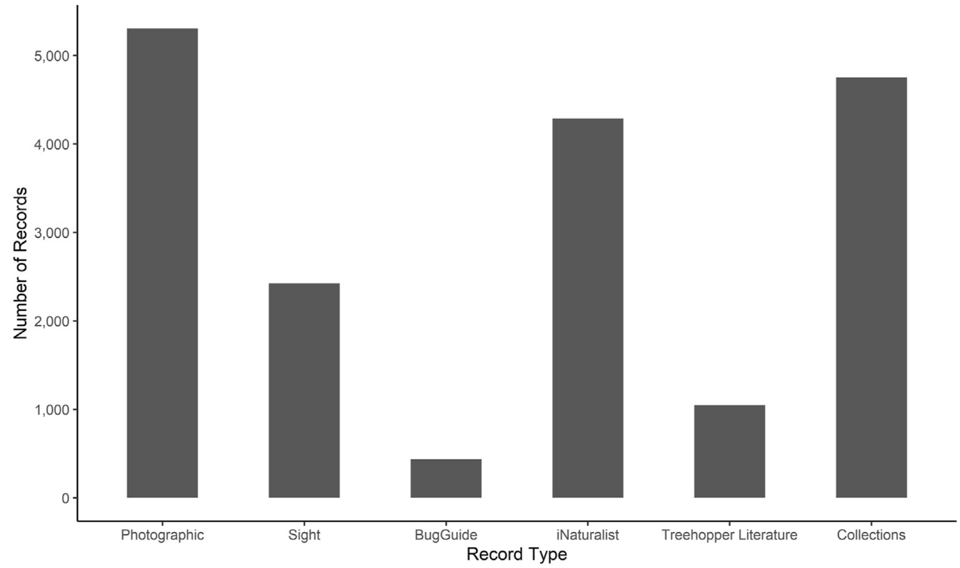

FIGURE 4 | The breakdown of the 18,256 records entered into the Hoppers of North Carolina site through May 12, 2021. There are 5,302 photographic (records that have at least one associated photograph), 2,425 sight, 436 BugGuide, 4,287 iNaturalist, 1,047 treehopper literature, and 4,749 records from collections (i.e., digitized collections, several in-state collections, and specimens in collections noted in other literature).

a result of KDK and SVH informing the public of whether photographs of the underside, measurements, or knowledge of the sex of a hopper are needed to make identifications for specific taxa, we have essentially trained some contributors to recognize these challenging taxa and therefore determine when they need to collect this additional information to assist with identification. Some citizen scientists have even learned to recognize when some taxa require dissection of a collected specimen to determine the species. This is highly important, as many hopper groups cannot be identified through photographs alone. Interacting with citizen scientists in this manner helps filter the noise from the plethora of uploads and strengthens the overall quality of the data.

Additionally, engaging with the public on these online platforms can be useful when a noteworthy taxon is found, whether a state or country record, a potentially undescribed species, an unknown nymph, or a poorly known and infrequently encountered species with little to no prior available photographic documentation online. Not only are we able to recognize when a hopper may be something special, but we are also able to instruct citizen scientists on how to proceed with documenting these records. Through our correspondences we have had a number of people either take additional photographs or provide information such as the host plant of what might be noteworthy records. In some cases, people have collected specimens for us or our contacts. While many hoppers can indeed be identified from pictures alone and therefore do not require being collected, our interactions with hopper enthusiasts can help lead to selective collecting when appropriate. For example, the first author noticed a series of photographs on iNaturalist of a strange *Clastoptera* species from Louisiana and asked the observer to collect and send off several specimens for dissection; initial analysis of the specimens suggests that this is an undescribed species (**Supplementary Table S2**).

We also emphasize that these engagements and contributions of citizen scientists and citizen science platforms be properly recognized in the literature (Wilson et al., 2020), as a majority of citizen-science collected data does not get referenced in peer-reviewed literature (Theobald et al., 2015). For one state record in the literature (Leavengood et al., 2017), which was first posted by a user on BugGuide (*Asarcopus palmarum* in Texas), the online platform was not mentioned in the publication. While the person that found the record was included as an author in the paper, we suggest that the online source of the record also be included in these kinds of publications (see other literature in **Table 1**) in order to help recognize the value of these citizen science platforms in entomology.

We also recommend that researchers develop better approaches to disseminating knowledge and expertise to the general public. Some of this dissemination can come through interactions online with citizen scientists, or even by contributing knowledge to the "Info" pages on BugGuide (see Methods, *Citizen Science Background*). Unlike charismatic biodiversity such as birds or even butterflies and odonates, much of the literature on hoppers remains scattered and hard to access, and most species lack high quality and/or correctly identified photographs online. Therefore, we stress the need for the development of photographic libraries of different species, particularly of specimens representing infrequently and poorly known species. The *Hopper Site* serves as a great example of what can be possible in addressing these issues, with a layout that effectively disseminates knowledge from the literature and displays multiple photographs of species that can aid the public in identification of different sexes, forms, subspecies, and life stages of species.

Finally, as with any form of citizen science, there is a certain inevitability for inaccuracies and an overzealous pursuit of precision without intervention. As mentioned earlier, the engagement of researchers can help to mitigate this, but there are also actions that citizen science websites can take to ensure more accurate and scientifically useful results. First of all, we recommend that citizen science sites discourage users from making initial species-level identification without input from a knowledgeable expert, especially for challenging arthropod taxa. Likewise, we recommend sites diverge away from the recent inclination to use AI to make species-specific identification beyond family-level; we have seen firsthand on iNaturalist that the AI is just too inaccurate for many hoppers and it often leads to misidentifications, even when drawing from larger datasets. Sites should also verify experts through a simple review of credentials, and experts should consequently make their knowledge and area of expertise clear through their site profiles. We also encourage platforms to increase the number of default fields for data entry, such as size, plant/animal association, quantity observed, and habitat (see *Hopper Site*) to ensure more accurate identifications of arthropods. Lastly, we recommend that these sites create designated areas for the clear and concise relay of important information regarding identification. Such an area of the site should be foremost for each taxon and immediately accessible to any user, with clear information about how to differentiate very similar taxa (see *Hopper Site*).

DISCUSSION

Citizen science can play an especially important role in advancing the research and monitoring of under-studied biodiversity (Amano et al., 2016; Chandler et al., 2017; Theobald et al., 2015), particularly arthropod taxa such as hoppers. At a time when there is increasing concern among entomologists about a significant global decline of insects (Montgomery et al., 2020; Wagner et al., 2021), citizen science can be effective in monitoring insect populations on as wide a scale as possible, while also affording copious sample locations and coverage that even the most extensive studies would struggle to replicate. Being a suborder of one of the most diverse and speciose insect orders in the world, while also in great need of further study, makes Auchenorrhyncha an optimal candidate for this analysis.

Contributions from citizen scientists are also leading to important discoveries of both described and undescribed species that help increase our knowledge of the natural world. We found 11 publications that mentioned country records, state records, or recently described hopper species for 18 taxa that were found and documented by North American citizen scientists (**Table 1**), with a couple of other publications noting contributions of citizen scientists towards an improved understanding of the natural and evolutionary history of Auchenorrhyncha (Hamilton, 2011, 2012). In comparison, there are notable first country or state records of 24 taxa submitted to BugGuide and iNaturalist that have not yet been recognized in the literature (**Table 2**). We also have compiled a list of undescribed or potentially undescribed hopper taxa that were discovered and documented by the public (**Supplementary Table S2**), helping underscore the value of citizen science contributions to the study of Auchenorrhyncha. Furthermore, within the last 2 decades, the number of photographic hopper observations posted online by citizen scientists has exponentially grown annually (**Figure 2**) and is equivalent to approximately 58% of all hopper specimens in digitized collections in continental North America (**Figure 1**), emphasizing the impressive spatial and temporal scale of data collection by members of the public. Additionally, we show that accelerating growth in citizen science data collection in recent years is not restricted to just birds (Amano et al., 2016), as there is a clear acceleration in enthusiasm by the general public photographing and uploading sightings of hoppers in at least North America (**Figure 2**).

In North Carolina alone, submissions by the public have greatly expanded the knowledge of hopper distribution and abundance in the state, with hundreds to thousands of county records (Kittelberger and Howard, 2021) and 53 first state records since 2008 (**Supplementary Table S3**). The invaluable contributions of the public to helping provide a much better understanding of the number of hopper species that occur in North Carolina serves as a microcosm for the important hopper documentations people are making in the rest of North America. Furthermore, citizen science records on these platforms have helped confirm the presence of previously published records in parts of North America, sometimes many decades after the last reported sighting or collection date. For example, the leafhopper *Allygus mixtus* (**Figure 3D**) was recorded from Massachusetts in 1919 and subsequently assumed to have died out after no new records had been reported for almost a century (Hamilton, 1983). However, the species was rediscovered in the state in 2017 based on BugGuide records.

Data from citizen science records has also provided us with information pertaining to large range expansions of both native and introduced species. The adventive *Curtara insularis* (**Table 2**), officially recorded in Florida in 2009 (Halbert, 2009) and subsequently found in BugGuide records for the state dating back to 2004, has experienced a rapid range expansion throughout the southern United States and into Nearctic Mexico within the past several years (i.e., first recorded in North Carolina in 2017). While this massive expansion seems to have evaded the scientific press for over a decade, the current distribution of the species is quite evident through citizen science records. *Pagaronia minor*, introduced from Japan and first discovered in North America in New York in 2005 (Hamilton, 2011), has also seen a fairly rapid range expansion in recent years, now ranging south into the mountains of North Carolina (first record in 2014). Likewise, the introduced African planthopper *Tarophagus colocasiae* recently expanded west from Florida into Louisiana and is now well established in the coastal part of the state (**Table 2**).

The citizen scientists that share observations from either side of the United States-Mexican border are also of great benefit to the entomological community, and many country records and potentially new species have been recorded by photographers near the border (**Table 2**). People in the southernmost regions of Texas have obtained many new records for the United States, including *Aeneolamia contigua*, *Cephisus cf. brevipennis*, *Anotia firebugia*, *Egidemia cf. inflata*, and *Graphogonalia cf. evagorata* (**Table 2**). Some of these records are somewhat predictable occurrences based on known ranges (*Aeneolamia contigua*, *Graphogonalia cf. evagorata*) while others are rather notable jumps from previously known ranges (*Anotia firebugia*, *Egidemia cf. inflata*). Across the border in Mexico, citizen science records on iNaturalist can offer insight into potential future additions to the North American hopper fauna. These potential future records by means of northward range expansion could include *Apogonalia monticola*, *Draeculacephala clypeata*, *Draeculacephala soluta*, *Oncometopia clarior,* and *Paraulacizes thunbergi*.

While the focus of our study is on the United States and Canada, we found many references to citizen science contributions in hopper papers outside North America, especially in regards to iNaturalist in Europe. For example, iNaturalist has been instrumental in tracking the spread of the planthopper *Acanalonia conica* throughout the Western Palearctic (Holzinger et al., 2020; Pélozuelo et al., 2020). The global focus of iNaturalist is crucial to understanding the spread of certain problematic species that have a high risk of spreading worldwide, such as the highly destructive Spotted Lanternfly (*Lycorma delicatula*) in the Eastern United States. Observers within the past 2 years have also discovered the likely presence of the Korean Typhlocybine leafhopper *Tautoneura polymitusa* in Missouri (**Table 2**) as well as in various countries in the Western Palearctic (Tóth et al., 2017; Gubin et al., 2020; Kosovac et al., 2020), indicating a new and poorly-known introduction to temperate regions. Catching these sudden introductions of species before they become well established and verifying their presence is crucial to preventing significant ecological and economic damage in the future.

As the number of people contributing to citizen science continues to rapidly expand (**Figure 2**), it is important to capitalize on the growing value of the entomological curiosity shared by these amateur naturalists, particularly the younger generations (Generations Y and Z) of contributors to sites such as iNaturalist which tend to have a preference towards documenting arthropods (Aristeidou et al., 2021). As of 2019, there were 25 million records of biodiversity representing more than 230,000 species that were documented by over 700,000 people on iNaturalist (Seltzer, 2019), numbers that will only continue to grow as the platform and its impact extend further (**Figure 2**).

We have provided a series of recommendations in this paper to the entomological community on how to approach data collected through citizen science. Not only can experts support and help foster passions to document nature through correspondences with the general public, but we can play an important role in the curation of data by providing and vetting identifications of observations submitted to platforms such as BugGuide and iNaturalist. We have the ability to help teach amateur naturalists how to properly document various species for identification purposes by informing them when details such as appropriate morphometric information or photographic angles are needed to make a species identification. Likewise, we can use this passive surveillance of arthropods to ask people to selectively collect specimens to aid our efforts to catalog the entomological world. However, we also believe that citizen science websites can help play an important role in ensuring a higher standard of data submitted by the public, through efforts such as moving away from a reliance on artificial intelligence. With a proper understanding of how to distinguish between species and noting what identification challenges exist for specific taxa, it is possible to use digital photography and the contributions of citizen scientists to advance our knowledge of the biogeography and natural history of arthropods (Goula et al., 2013).

Finally, we believe that the *Hoppers of North Carolina* website is a revolutionary tool for identifying hoppers, serving as the most comprehensive and informative website covering any state's hopper fauna in the United States. It has a modernized approach to identifying these insects, with a focus on disseminating knowledge of these taxa to the public and guiding users through hoppers and how to identify them (Kittelberger and Howard, 2021). The site incorporates information from hundreds of publications and taxonomic sites, information that is not necessarily easily accessible or well known to the general public. It also has amalgamated records from a variety of sources, including BugGuide, iNaturalist, and iDigBio, ensuring that it is as authoritative as possible in representing the knowledge of any spittlebug, leafhopper, treehopper, or planthopper found in the state. The *Hoppers of North Carolina* site can help serve as a model for current and future websites that function as interactive photographic field guides, records databases, and citizen science platforms—not only for Auchenorrhyncha but for arthropods and other lesser-known taxa.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

KK and SH wrote the manuscript, with input from ÇŞ; KK conceived the original idea for the paper; KK conceived the idea behind and is the author of *Hoppers of North Carolina*, for which KK also acquired funding and resources; KK and SH compiled the data for this paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.710396/full#supplementary-material.

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Connecting Community and Citizen Science to Stewardship Action Planning Through Scenarios Storytelling

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Community and citizen science on climate change-influenced topics offers a way for participants to actively engage in understanding the changes and documenting the impacts. As in broader climate change education, a focus on the negative impacts can often leave participants feeling a sense of powerlessness. In large scale projects where participation is primarily limited to data collection, it is often difficult for volunteers to see how the data can inform decision making that can help create a positive future. In this paper, we propose and test a method of linking community and citizen science engagement to thinking about and planning for the future through scenarios story development using the data collected by the volunteers. We used a youth focused wild berry monitoring program that spanned urban and rural Alaska to test this method across diverse age levels and learning settings. Using qualitative analysis of educator interviews and youth work samples, we found that using a scenario stories development mini-workshop allowed the youth to use their own data and the data from other sites to imagine the future and possible actions to sustain berry resources for their communities. This process allowed youth to exercise key cognitive skills for sustainability, including systems thinking, futures thinking, and strategic thinking. The analysis suggested that youth would benefit from further practicing the skill of envisioning oneself as an agent of change in the environment. Educators valued working with lead scientists on the project and the experience for youth to participate in the interdisciplinary program. They also identified the combination of the berry data collection, analysis and scenarios stories activities as a teaching practice that allowed the youth to situate their citizen science participation in a personal, local and cultural context. The majority of the youth groups pursued some level of stewardship action following the activity. The most common actions included collecting additional years of berry data, communicating results to a broader community, and joining other community and citizen science projects. A few groups actually pursued solutions illustrated in the scenario stories. The pairing of community and citizen science with scenario stories development provides a promising method to connect data to action for a sustainable and resilient future.

Keywords: action science, climate change learning, environmental education, futures thinking, resilience thinking, scenarios development, youth

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INTRODUCTION

Community and citizen science on climate change-related topics offers a way for participants to actively engage in understanding the changes and documenting the impacts (Dickinson and Bonney, 2012; Pecl et al., 2019). Community and citizen science spans a spectrum of collaborations between public participants and professional scientists in conducting scientific research, from "contributory" program designs where public are involved only in data collection to "co-created" projects where scientists and community members collaborate on all or most phases of the research (Shirk et al., 2012; Bonney et al., 2014). In large scale contributory projects, where participation is primarily limited to data collection, it is often difficult for volunteers to see how the data can inform decision making that can help create a positive future. Further, in vast climate change-related contributory projects, the majority of participants feel powerless to act on such big, complex issues (Jordan et al., 2011).

This is not the case in smaller scale, co-created environmental projects, which tend to be created with the intent for action or self-advocacy and allow for more rapid and visible use of the data for decision making and policy changes (Danielson et al., 2010; McGreavy et al., 2016). Much research and program design innovation is still needed to create visible linkages between the data volunteers have collected in contributory programs and how the data can be used for the future beyond the scientific publications and program newsletters.

This is particularly true in youth-focused citizen and community science programs, where educators are seeking to help develop a sense of agency in their youth, but youth often aren't able to make the connections between the act of data collection and how it can contribute to the future (Ballard et al., 2017). Many studies show that children and youth in the current generation have pessimistic visions of the future in a changing climate (Hicks and Holden, 2007; Naval and Reparaz, 2008; Threadgold, 2012), and that the pessimism tends to increase with age as youth come to realize the complexity of the global climate change issue (Eckersley, 1999; Hicks and Holden, 2007). Late childhood and early adolescence are pivotal periods for the development of the hope and sense of agency that can either hinder or support the growth of their desire to seek knowledge and their competencies for sustainability action (Ojala, 2012). In this paper, we test a method of initial steps in scenarios stories development within a large youth-focused contributory citizen and community science program. The method is designed to link the youth's science process and data collection to a positive vision of the future and concrete local stewardship actions that they could plan and implement.

Determining a plan for the future is a challenging task in any context, and is a skill that must be practiced. Scenarios story development is a strategy that has risen in popularity within the climate change adaptation and planning field, and is a process of taking the information available, asking "what if?", and articulating stories to these possible futures that can directly inform planning, decision-making, and stewardship action (Mietzner and Reger, 2005; Millennium Ecosystem Assessment [MEA], 2005; Carpenter et al., 2006; Amer et al., 2013). The steps for scenarios planning involve: (1) reviewing current and past knowledge of the environmental issue, (2) defining a focal question and relevant time frame for the scenarios, (3) identifying forces and factors that have an effect on the focal question, (4) identifying the critical uncertainties, (5) developing the characteristics of multiple possible scenarios based on different actions pursued, and (6) determining the implications of the different actions taken in the different scenarios and prioritizing actions based on this assessment (O'Brien, 2004; Amer et al., 2013). The scenarios story development process can be greatly informed by citizen and community science data. For example, steps one through three can be informed by the data collected and step four can be pursued using citizen and community science methods to collect further data needed to address the uncertainties.

The practice of envisioning and planning for the future in youth environmental education has been studied with more frequency over the last 25 years. In one repeat study in the south of England conducted in 1994 and then again in 2004, Hicks and Holden (2007) asked 11 and 14 year olds about their hopes and fears for the future at a personal, local and global scale. The youth demonstrated concern and knowledge about present-day activities both damaging and improving future conditions. The study guagued the ability of futures-oriented teaching practices to enable students to imagine the future and to facilitate students' understanding that their actions were important and mattered in determining pathways to the future (Hicks and Holden, 2007). Other studies have more specifically documented the application of scenario stories in youth settings. Lloyd (2011) employs scenario story writing in two undergraduate courses in the geosciences. Lloyd writes, "Futures scenarios provide starting points for action that preserves what is good and changes that which is bad, evil, or unsustainable. They develop foresight, assist in deep and meaningful learning, promote behavioral change, are empowering (an aspect of well-being) and develop creativity" (Lloyd, 2011, 99). Scenario exercises were also applied in Chalaco, Peru with 11–13 year olds to consider the conservation and futures of Chalaco's resources, watershed and mountainous ecosystem by The Sustainable Development Mountain Ecosystem Programme (PDSEMP in Spanish). Interestingly, limitations were identified in these age group's perceptive ability to think 5–10 years into the future. PDSEMP, too, had to simplify the process in order to focus students' attention on the key takeaways from what thinking about the futures is intended to elicit (Velarde et al., 2007). This process has been used with youth to help bring youth voice to community planning in the Arctic Future Makers project (Cost and Lovecraft, 2020). Cost and Lovecraft (2020) found that high school-aged youth were adept at identifying key factors that impact their community's ecosystem (steps 1–3), but had a more difficult time imagining the future.

As demonstrated in these studies, futures thinking and scenarios development exercises are useful strategies to empower youth to think more strategically while relying on the best knowledge to date to better inform decision-making (Hicks and Holden, 2007; Velarde et al., 2007; Lloyd, 2011; Cost and Lovecraft, 2020). We sought to employ a brief sample of the scenarios story development process to see if we could draw a connection between the gathering data in a community and citizen science project and using it to inform imagining possible futures and laying a pathway to a desirable future. We also saw the combination of these two activities as a way for youth to practice the thinking skills necessary for navigating a rapidly changing environment (Spellman, 2015).

Both the social-ecological resilience and education for sustainability literatures agree on several thinking skills that are key to building the collective ability of communities to adapt to and shape change (reviewed in Wiek et al., 2011; Spellman et al., 2016). We refer to these skills as "resilience thinking skills," which we define as higher order cognitive skills that support problem solving in a social-ecological system context. The key resilience thinking skills include the ability to interpret and apply new scientific information to novel situations (Carpenter, 2002; Folke et al., 2003; Fazey et al., 2007), systems thinking (e.g., the ability to consider both social and ecological aspects of a problem and how they interact; Sterling, 2005; Meadows, 2008; Crawford and Jordan, 2013; Hmelo-Silver et al., 2017), futures thinking (e.g., the ability to think about future events or future desired ecological states and anticipate the consequences of present actions taken by humans; Ascher, 2009; Tschakert and Dietrich, 2010; Tidball and Krasny, 2011), and sense of human agency (e.g., the ability to understand the agency of humans within the ecosystem and imagine strategies to move toward a desired social-ecological state; Brundiers et al., 2010; Wiek et al., 2011; Ballard et al., 2017). In youth environmental and science education programs, the suite of these thinking skills could be addressed through the novel pairing of citizen science engagement and scenarios storytelling.

We see great potential for using scenarios story development in conjunction with youth-focused citizen and community science as a way to facilitate youth directly linking their data with hope for a positive future, practicing resilience thinking skills, envisioning a pathway for action, and imaging themselves as agents of environmental stewardship action (**Figure 1**). In this paper, we demonstrate this method across diverse youth groups involved in a wild-berry focused citizen and community science program. In our demonstration of this method, we explored the following questions:

- Does using scenarios storytelling allow youth to exercise resilience thinking skills?
- Does scenario storytelling allow youth to picture themselves as agents of change in the ecosystem?
- Does the extent to which the activity exercised these outcomes (resilience thinking skills demonstrated and youth picturing themselves as agents of change) vary by community setting and grade level?
- What value did the educators perceive in using scenarios storytelling to culminate the citizen and community science experience for their youth group?
- Did educators report that youth groups pursued stewardship actions after the activity? If so, what types of actions were pursued?

MATERIALS AND METHODS

Study Setting

We tested our method of pairing community and citizen science with scenarios storytelling with thirteen youth groups and a total of 170 youth who participated in the Winterberry Citizen Science program across Alaska (**Table 1**). Six youth groups from 5 rural (defined as communities with population <2,500; U.S. Census, 2010) predominantly Alaska Native villages and seven urban (population >2,500) youth groups from two towns tested the method across a variety of age groups and learning settings. The groups spanned formal and informal learning settings and three grade levels we categorized as primary grades (ages 5–9; five groups), intermediate (ages 9–12; four groups), and secondary (ages 13–18; four groups) (**Table 1**). Grade level categories were based on the groupings within the rural village schools and youth programs included in the study, which had multiage classrooms or youth groups due to small village populations within this study (range 83–1405 people; U.S. Census, 2010).

In the Winterberry Citizen Science program, youth groups and adult volunteers collaborated with University of Alaska ecologists to investigate the influence of the changing timing of the growing season on four native species with fleshy fruits (Alaska wild rose–*Rosa acicularis*, lowbush cranberry–*Vaccinium vitis-idaea*, highbush cranberry–*Viburnum edule*, and crowberry–*Empetrum nigrum*) commonly referred to as "berries" throughout the state. The species were selected because (1) they are important species for subsistence and recreational harvesting across Alaska, (2) they are widely distributed throughout the state, and (3) they retain a high proportion of fruit in the fall and winter. Each volunteer group marked and "adopted" twenty or more individual plants with a minimum of 100 berries and tracked the abundance and condition of the berries (ripe, rotten, damaged by frugivores, or dried) on each plant in fall and spring,

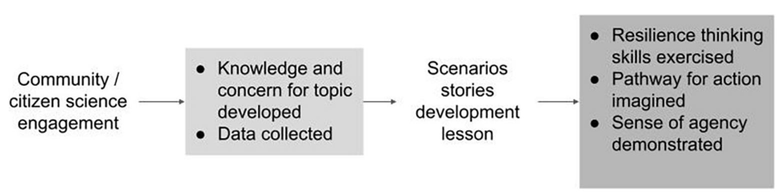

FIGURE 1 | Proposed theory of change model for youth concluding a climate change-related community and citizen science project with a scenarios development mini-workshop.

TABLE 1 | Resilience thinking rubric scores for youth work samples of scenario stories created with Winterberry Citizen science data and berry stewardship action brainstorming.

	No. groups	No. youth	Resilience Thinking Rubric Score				
			Applied CS data (±s.e.)	Systems Thinking (±s.e.)	Futures Thinking (±s.e.)	Human Agency (±s.e.)	Total (±s.e.)
Setting							
Rural	6	46	2.2 (±0.2)	1.9 (±0.3)	2.1 (±0.2)	2.0 (±0.2)	8.2 (±0.7)
Urban	7	124	1.8 (±0.1)	1.7 (±0.2)	1.9 (±0.1)	1.7 (±0.1)	7.1 (±0.4)
Grade Level							
Primary	5	54	1.9 (±0.1)	1.9 (±0.2)	2.0 (±0.2)	1.8 (±0.2)	7.5 (±0.7)
Intermediate	4	71	1.9 (±0.3)	1.7 (±0.6)	2.0 (±0.3)	1.8 (±0.2)	7.3 (±1.0)
Secondary	4	45	2.1 (±0.3)	1.8 (±0.3)	2.1 (±0.1)	1.9 (±0.1)	7.9 (±0.8)
All groups	13	170	2.0 (±0.1)	1.8 (±0.2)	2.0 (±0.1)	1.8 (±0.1)	7.6 (±0.4)

and monitored snow pack depth monthly in winter using the Global Learning and Observation to Benefit the Environment (GLOBE) protocol (**Figure 2A**; Spellman et al., 2019).

This study falls within the context of a larger research program which is experimentally testing the effects of storytelling-based pedagogies in community and citizen science using a controlled study design. Youth and educators in the storytelling treatment group completed the program with storytelling activities before monitoring berries, during, and after monitoring berries. We compared individual and programmatic learning outcomes to similar groups from similar learning settings and age groups that received the same instructional level of support but framed through standard science inquiry teaching practices. The scenarios storytelling method was used as the final phase in this model. The overarching study used a pre–post design and we could not extract the individual influence of the scenarios method from this controlled study, as the pre–post design encompassed all three storytelling components. The overall effects of the storytelling-based learning cycle for community and citizen science will be presented in a forthcoming manuscript. We present here the available data that could solely address the impact of scenarios storytelling without the influence of the other storytelling methods, as a start to investigating this strategy in more detail and laying groundwork for future study.

Lesson Delivery Method

In the spring after the final data collection had occurred, one scientist and one master educator from our program team delivered hour-long berry data “jam sessions” and scenarios story development activity with each of the thirteen youth groups to explore the data from throughout the state. During the sessions, youth looked at the condition and abundance of berries using the data they collected at their own field site and compared them to data collected at other sites by other volunteers from at least three other bioclimatic regions in Alaska (**Figure 2B**). Guided by program scientists in a space-for-time substitution exercise, they used temperature and precipitation projection scenarios from their own region (Scenarios Network for Alaska and Arctic Planning [SNAP], 2021) and used patterns from the citizen science data in bioclimatic regions similar to the projections (**Figure 2C**) to imagine 20 years in the future.

Based on the data and their knowledge of the sites, students brainstormed what key factors and trends might impact the berry harvests in their community. These lists provided the foundation for the students to imagine what future berry harvest might look like. Students sketched or wrote two contrasting scenarios for the future of berries at their field site or in their community: (1) a do-nothing, business-as-usual future and (2) a “best” berry future. Students began with the do-nothing future, and imagined a scenario with warmer and wetter fall seasons with increasingly rotten, damaged or missing berries as indicated by their datasets they examined (**Figure 2D**). They were prompted by the questions, “What is the data suggesting could happen to our berries?” and, “What will you and the habitat look like 20 years from now?” The students were then prompted to brainstorm ideas for creating different futures, where actions were taken to ensure enough berry resources were available for future generations. Each student thought of three to six actions that they or someone else could take and the ideas were discussed as a whole group (**Figure 2E**). Youth then sketched or wrote a new scenario story of a future where they had selected at least one of these strategies to actively create a new future. After listening to the contrasting scenario stories, students voted on which of the solutions seemed most important to pursue in reality (**Figure 2E**). Educators were not required to pursue the actions that the students agreed upon. The detailed lesson plan and materials are presented in Spellman et al. (2018).

The lesson plan adapted the youth-centered scenarios development scaffolds from Cost and Lovecraft (2020) by condensing some of the steps in the scenario planning process, and by reducing the number of scenarios from four to two. These adaptations allowed us to address the time block scheduling constraints of K12 classrooms and afterschool clubs and to apply the method across the various grade ranges involved in our citizen science program. They also allowed us to test the appropriateness of each strategy across the three different age groups. For each age level, we provided developmentally appropriate strategies to the activity, such as activity sheets modified for very young children and different type, which are documented in Spellman et al. (2019).

To demonstrate this method and explore its application and possible learning outcomes in formal and informal learning

FIGURE 2 | Method for pairing community and citizen science with scenarios storytelling. During the first phase of the activity, students reflected on the berry data they collected in their own field sites **(A)** and analyzed the patterns using graphs **(B)**. They compared the patterns in their site to three other sites in the citizen and community science project from other bioclimatic regions **(C)** to begin to imagine future scenarios of a "do-nothing future" and a "best berry future" **(D)**. Youth collaborators brainstorm strategies to foster a sustainable amount of berries for future generations to include in their scenarios, and prioritize the actions through a voting activity **(E)**. Full lesson plan available from Spellman et al. (2018).

settings, we assessed the activity's impact through educator interviews and analysis of student work samples. While we did conduct youth interviews as a part of our larger study, youth did not mention the scenarios stories exercise in their interviews. They unsurprisingly focused on the activities which they spent the vast majority of their project time on, outdoor data collection. We therefore isolate our data to the student work samples from the scenarios activity and educator interview sections that specifically addressed the scenarios storytelling to cross-validate the evidence.

Student Work

We collected scenario work from all 170 students across the thirteen youth groups. Because some of the groups chose to do the activity as small groups of students rather than as individuals, the total number of work artifacts was 126. Each work sample was evaluated by two reviewers for resilience thinking skills [(1) application of citizen science data to the berry harvest problem, (2) systems thinking, (3) futures thinking, and (4) human agency to act or make change] demonstrated through the activity using a three-point rubric adapted from the validated instrument used in Spellman et al. (2016). The rubric constructs consisted of the four resilience thinking skills listed in **Table 1**, and the rubric criteria spanned three rubric levels for a total of twelve possible points. The rubric is included in Appendix A.

The inter-rater reliability of the adapted rubric was determined by calculating the total rubric scores across the four thinking skills for the work sample, then comparing the scores of the two raters using correlation (Pearson's r). Reliability of each individual rubric item was calculated using Cohen's kappa. The evaluators (Cost and Spellman) first calibrated coding with each other by discussing the rubric scores they individually scored together and discussed differences in interpretation. One scorer (Spellman) had been involved in the delivery of the lesson with all but one of the groups, and conversations about the work with the youth enabled a different insight into the work, and generally led to scores one point higher than the scorer who had not interacted with the students. As a result, we averaged the two reviewer scores for each thinking skill and total score across skills. We then calculated averages across students in each youth group for all further analyses to avoid having urban classrooms with large sample sizes have undue influence on the analysis.

While the use of the rubric was intended to simply assess if resilience thinking skills could be exercised by students through this method, we were interested in whether the method could be applied across many different types of youth groups. To gather preliminary data on its application across age groups and settings, we conducted Analysis of Variance on the rubric scores to test for differences between samples that included group work and individual work, and for the influence of group size and group age range (many youth groups and classrooms in Alaska's rural villages span multiple ages due to very small population size) on the scores using Analysis of Variance. We used the four rubric thinking skills and the total resilience thinking score as the response variables. To better understand student views of themselves as agents of change, we collected additional data on the types of stewardship actions proposed, whether they pictured themselves as agents or beneficiaries of these actions.

Educator Interviews

Our external evaluator conducted post-participation semi-structured interviews of the educators leading each youth group, with eleven of the thirteen educators completing interviews. The interview protocol was a part of our larger citizen science program evaluation, and included a section about the data jam and scenarios storytelling activity. The questions in this section were designed to learn about the educator's perceived effect of the data jam and scenarios storytelling activity on the students and the effectiveness of the activity delivery by the program team. On these interview transcript sections, we coded them first according to the *a priori* resilience thinking constructs to triangulate evidence from the student work samples. We then conducted a thematic analysis as per Terry et al. (2017) for emergent themes. This process involved two researchers and followed a process of, (1) familiarizing ourselves with the quotes, (2) generating codes together, (3) developing themes through an iterative and collaborative process of examining the codes and associated quotes and combining or clustering codes into more general patterns, and (4) assigning themes to each of the quotes.

All statistical calculations were conducted in R studio. All work was formally reviewed and approved by the University of Alaska Fairbanks Institutional Review Board.

RESULTS

Youth Work Samples

Rubric Reliability

Total resilience thinking rubric scores were correlated (Pearson's $r = 0.55$), and Cohen's kappa for the four resilience thinking skills confirmed fair agreement between the two raters ($\kappa = 0.10$ use of citizen science data, $\kappa = 0.23$ systems thinking, $\kappa = 0.16$ futures thinking and $\kappa = 0.28$ human agency).

Demonstration of Resilience Thinking Skills

There was evidence of all four of the resilience thinking skills in the student work samples, with average rubric scores in all four constructs at or near a level two across all youth (**Table 1**). There were no significant differences in individual skill scores or total rubric between age groups or rural and urban learning settings ($p > 0.10$ in all cases). There was no significant difference in the total resilience thinking score if students worked cooperatively or individually in level of resilience thinking rubric scores ($F(1,123) = 1.34$, $p = 0.25$). Group size and number of grade levels within the classroom or youth group did not significantly influence the total resilience thinking rubric scores (group size $F(1,11) = 0.37$, $p = 0.55$; grade span $F(1,11) = 0.13$, $p = 0.73$).

Self as Agent of Action

55.6% of the all youth work samples included the youth themselves as agents of change in their scenario stories (70 of 126 samples; **Figure 2**), while 16.7% (21 of 126 samples) included themselves in their scenarios as beneficiaries of positive change with no indication that they themselves had played a role in it. 27.8% of the samples did not include the youth pictured or described in the scenario (35 of 126 samples). Grade level did not influence the percentages of students who pictured themselves as agents of change in their scenario stories (**Figure 3**; $F(1,11) = 0.1274$, $p = 0.73$). Rural youth tended to include themselves in the scenarios as agents of change at a higher percentage than urban youth (**Figure 3**), though this was not a significant effect. A higher percentage of the scenario stories included the youth themselves as agents of change if they worked on the scenarios as a group then if they worked on it as an individual (63% of group and 53.8% of individual work samples).

Of the youth work samples, 71% illustrated some clear action or strategy to sustain berries into the future taken by themselves or others (**Figure 4**). The most common action that the youth from both urban and rural settings and across age ranges decided to take in their scenarios were agricultural solutions with native subsistence berries species that they monitored (planting berries, berry greenhouses, etc.; **Figure 4**). Other action strategies included further data collection or new technologies to understand the impacts of climate change on berries and using traditional methods for ensuring berry availability in sparse years such as food preservation and berry trading with other regions of the state with different climate patterns. Some youth chose to create protected areas for berries or introduce new non-native berry species. General care for the Earth, such as not littering and "taking care of the berries" were suggested by early primary youth, while climate change policies and related actions were suggested by some of the older youth. While nearly all scenario stories illustrated clear differences between the do-nothing and the best berry future scenarios, 29% did not illustrate or describe an action taken.

Educator Perception

With regard to the activity exercising resilience thinking skills, the educator interviews generally corresponded with the assessment of the student work artifacts. The application of new data received the most attention from educators (21 mentions from 10 of 11 educators interviewed), followed by educator perception that youth exercised futures thinking (15 mentions from 9 educators). The educators also perceived youth practiced systems thinking and expressions of human agency in the social-ecological system, but to a slightly lesser extent than the other two resilience thinking skills (8 educators and 12 mentions, and 6 educators and 15 mentions, respectively).

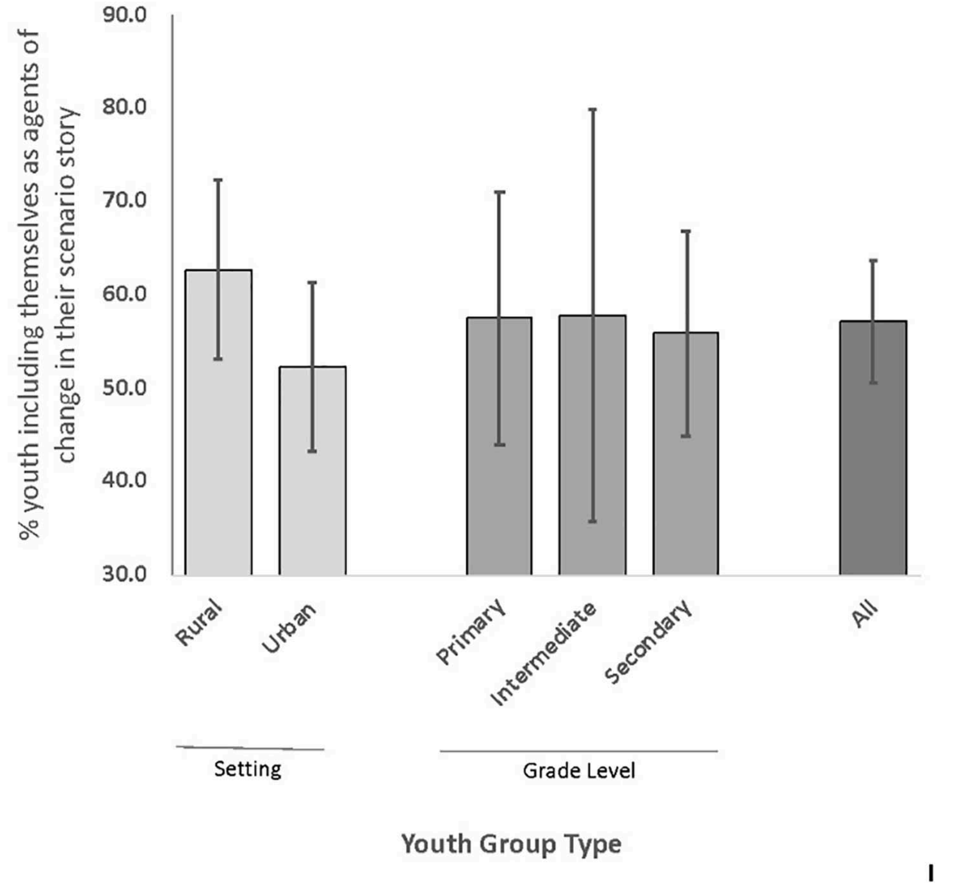

FIGURE 3 | Percentage of youth work samples (n = 126) illustrating youth themselves as agents of berry stewardship action from rural and urban Alaska learning settings and from different grade levels (primary = grades K-3, intermediate = gr. 4–6, secondary = gr. 7–12).

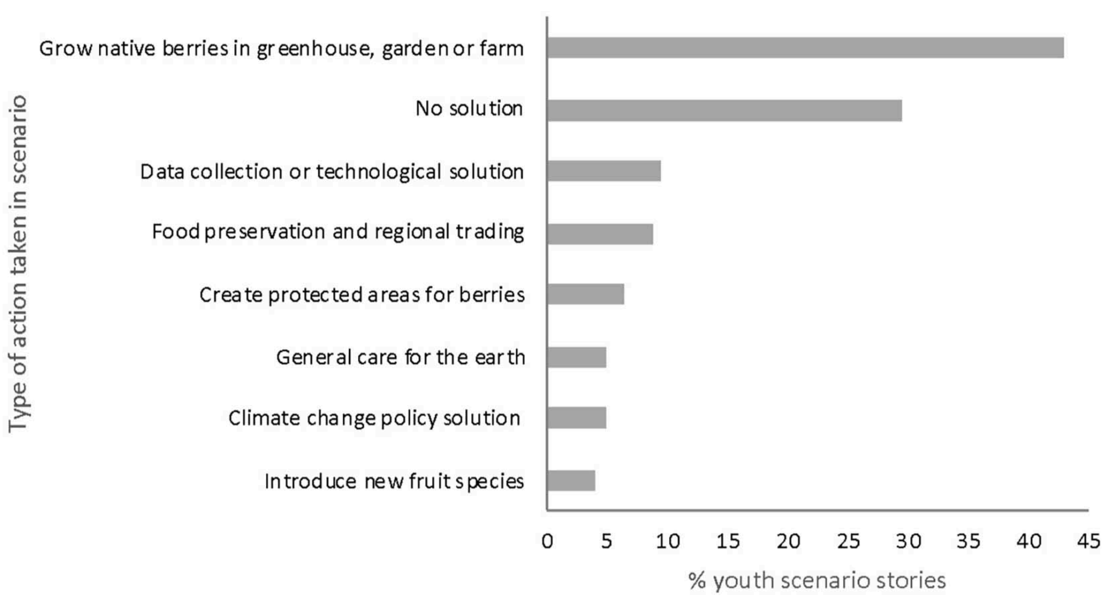

FIGURE 4 | Types of actions illustrated or described in the youth scenario stories (n = 126 youth work samples).

The emergent themes in the educator interviews clustered around two dimensions: (1) perceived effects of pairing community and citizen science with scenarios story development on youth and (2) perceived value of the activity to teaching practice.

Effects on Youth

The most mentioned effect on youth by the educators was that the students felt like they were a part of something bigger than themselves. The community and citizen science aspects of the project enabled the youth to realize they were part of a statewide Winterberry science effort and international network through the inclusion of GLOBE. The educators perceived that this, in combination with the scenarios stories activity, allowed the students to feel like they were a part of creating a positive future for their community. As one educator put it, "*The kids really bonded together in order to make the project very much their own, which is kind of cool considering that it's such a far flung project and involves so many areas within the state of Alaska and that it's science that's shared around the world. It's really cool that the students still felt like it was very, very much their own project. And then also felt that sense of greater community and participation because of all of the other areas where data is collected and the data is used.*" (Educator Interview).

As in this exemplary quote, the sense of "being a part of something bigger" was often mentioned in conjunction with a sense that the students felt empowered by the experience. Educators mentioned that the students were equipped to actually be scientists, change makers and stewards of the land. They saw the youth make decisions using data as they outlined a path to a positive future. "*It just got kids thinking about this future in a positive way. You know, it's not all doom and gloom but–so maybe when they do see berries in the future they will, you know, say, 'oh, yeah. We studied this. We need to take care of these.'*" (Educator interview).

Educators also frequently mentioned that they felt the combination of the berry data collection, analysis and scenarios stories activities enabled youth to connect their learning to their community, their culture(s) and their futures. Culturally important berry species, the focus of the data collection, was noted as the primary source of this connection. They valued the activity as a way to be connected to the land by planning to protect traditional food resources in a changing climate. This aspect was predominantly expressed by teachers in rural and Indigenous communities or Indigenous educators (5 of the 6 educators who mentioned this theme). For example, one teacher from a small remote village stated, "*They all had some little cartoon drawings there with the berries, and that's when they led into their discussion on sustainability and how are we sustaining our–making sure that we have these berries 20 years from now, 50 years from now, in their future. They went through all that, overharvesting, can we plant them, do they just grow naturally? How do we preserve them? How do we use them in our foods? Cultural reasons they're valued. We invited the community up for some cranberry bread. The kids were showing off their data, and they were making more of those picture scenarios for them and kind of promoting [.] taking care, being stewards of the berry.*" (Educator interview).

Other examples included connections to Indigenous foods and language, connecting words of the Elders to the data and to the future, and communicating the results and the scenario stories back to their community or at professional science meetings.

Value to Teaching Practice

The educators who tested this method all perceived desirable teaching practices that resulted from this novel combination of community science and scenarios stories. Most frequently mentioned was the physical presence of a scientist during the delivery of the workshop. The educators thought this was valuable to the practice because the physical presence of the scientist showed youth they were part of something substantial and collaborative with scientists and an effort bigger than themselves. "*The most valuable thing was just them being here as the chief scientist of these projects, and that made an impression on the kids. And the other impression was that I think [the scientists] are very good at making sure that kids understand that they are also scientists, citizen scientists, and they're being stewards, so to speak, of maintaining the data collection and maintaining the integrity of the protocols.*" Additionally, the teachers noted the value of having the additional adults working with the youth to implement the activities. An urban educator stated, "*The most valuable aspects of the work was the scientist coming into the classroom and doing those story activities with those materials directly relating back to the project. That was very valuable because that helped place it into a larger context, not that I can't–I mean, I can certainly–I'm certainly capable of doing that on my own, but you know, the amount of requirements in lesson planning that I have to do on my own behalf makes trying to do these–you know, make a whole 'nother project happen really difficult. So any support that can come from outside to make those things happen is great.*" To do citizen science in youth learning settings well, the educators valued collaboration from outside of the classroom and external support for the science knowledge base and adult to student ratio.

They appreciated that combination of community science and scenario stories creating something "tangible" for the youth. Tangible in the sense that the activities facilitated students moving, learning outside, and using their hands by both counting berries weekly, and by sketching their possible futures and voting on the most important stewardship actions. Tangible also in the sense that the activities related climate change concepts in a way that was real, site-based, and approachable. One teacher stated, "*They just do an amazing job with students, and they were just a breath of fresh air when they came in and made science seem simple, but you know it's technical stuff.*" The climate change impact was easily imaginable in the berries they counted, in the graphs from other communities by youth in other parts of Alaska, and in the climate projections. The solutions the youth brainstormed were real and, for the most part, possible.

The educators appreciated that the pairing of activities was interdisciplinary and applicable across a wide range of ages. The community science data collection on berries combined with the scenarios story strategy allowed them to connect the project across content areas and standards for classroom teachers, or program priorities for afterschool programs (4-H, Boys and Girls Club, etc.). One classroom teacher mentioned, "*We've used it to further develop graphing skills, math skills, looking at data collecting, finding mean and average, you know? All that stuff. Writing. We've been using it in writing. We started the year out with personal narratives, so that they could create those berry narratives that they did* [. . .]" Educators noted that the activity utilized math, science, art, geography, and language arts and could be easily connected to ongoing or current learning and activities within their classroom or clubs. This approach made it an easy fit for addressing cross cutting concepts and themes, such as those emphasized in the Next Generation Science Standards in classrooms or priority youth development goals in youth clubs. In another example, one educator highlighted the concept of stability and change through time: "*Those numbers change and just trying to find patterns and trying to find some connection, some key. I mean we know–you know, we keep telling the kids that it's not what it used to be, you know, that's what we know from the Elders and from people that have been here forever. We know it's not what it used to be but maybe we can see where it's going and what we can do to make it better*." This example both highlights the cross-cutting concept in science education standards, but also how it can be applied to the future. Another afterschool club educator mentioned connecting the experience to healthy eating and diabetes, a priority concept for the rural Boys and Girls Clubs.

The evidence from the interviews also indicated that the activities were applicable across the K-12 age range, and appreciated the easy adaptations that the program provided to accommodate older or younger children. For example, an educator of 5 and 6 year old children stated, "*[The scientist] went around before she passed them out and drew a little sad face on the right and a smiley face on the left [for the better future]. And that was a good adaptation that worked out great*." While in a free-choice learning setting, youth of different ages gravitated to different aspects of the activities, "*It really depended on the age groups like I said, the middle schoolers, high schoolers were more into the social thing [.] The younger ones seem more interested in the data and locations and stuff like that*." In this case, the older students prepared berry muffins for a community story sharing event, while the younger students prepared the data and scenario stories.

From Participating in Science to Stewardship Planning and Action

In addition to the very high percentage of individual youth who successfully planned a pathway to action within their scenarios, all the youth groups were able to prioritize an action strategy across the whole group that seemed the most worthy of investment. Of the thirteen youth groups with whom we piloted this method, eleven of the groups (spanning the entire age range) hosted or participated in community nights or presented at Tribal or community council meetings. Partnership with the Winterberry program team was critical to most of these events. Three groups (two secondary and one intermediate aged) went on to present their work at professional environmental science meetings within Alaska or at a GLOBE regional student research symposium.

Of the strategies identified by the youth for sustaining berries into the future, three strategies were actually implemented by the groups: food preservation, agriculture, and continued monitoring. Two groups preserved berries for lean berry years through jams or drying, and one group planted new cultivars of berries in their school garden to test berry production and fruit condition compared to the wild berries in their school yard. Twelve of the thirteen groups continued to monitor berries through the Winterberry program for at least one additional year, which was expected for the program. Surpassing the program expectations, nine groups continued for three or 4 years, with several educators joining multiple community science projects offered by the University of Alaska Fairbanks team. For example, several educators have joined our ice monitoring program and joined GLOBE to use community and citizen science as a way for their youth groups to investigate other locally relevant topics like changing river and lake ice, water quality in their salmon streams, and soil moisture in tundra habitats.

DISCUSSION

Our results suggest that pairing community and citizen science with scenarios stories in youth-focused programs is a promising method for connecting the data collected to thinking about and planning for the future. We found that the method could be applied usefully across the full K-12 age range, and in diverse learning settings – from small, rural, multiage after school clubs and classrooms in Alaska Native villages, to large urban single grade classrooms with highly diverse student populations. The method afforded the range of students the opportunity to exercise the critical futures thinking skills and competencies proposed by the literature for navigating a rapidly changing climate. Both the educator interviews and the assessment of youth work samples showed that the method provided opportunities for youth to use and apply scientific data, practice systems thinking and futures thinking, and demonstrate human agency in the social-ecological system.

Youth are an important key to the present and future of climate change justice, science, and action (Gibbons, 2014). While climate education programs often have a polarizing effect on adults (Moser and Dilling, 2007), they do not on children and youth, who tend to increase in hope with greater exposure to climate change education despite differences in worldview and socio-ideological background (Stevenson et al., 2018). Further, children can foster intergenerational learning within their families that can overcome socio-ideological barriers to climate change learning among parents and adult caretakers (Lawson et al., 2019). The rapid growth and development of youth, too, has interesting parallels with the rapidly changing ecosystems (Cost and Lovecraft, 2020). Youth are in the midst of change themselves, and may have greater flexibility in cognition, imagination, and adaptation in their response to the changing environment than adults.

Our results from testing this method, however, indicate that thinking about actions to create a positive future in a changing climate is a skill that needs to be practiced. 29% of the youth work artifacts did not include a solution or stewardship action strategy and only 55% explicitly illustrated or described themselves as an agent of change in their scenario stories, despite both being explicit in the lesson instructions. Similar results emerge in other studies of youth engaged in scenarios development (Cost and Lovecraft, 2020; Velarde et al., 2007), futures thinking (Hicks and Holden, 2007) or community and citizen science (Ballard et al., 2017). Youth have a difficult time imagining actions that will make a difference for the future (Cost and Lovecraft, 2020; Velarde et al., 2007; Hicks and Holden, 2007). Similarly, understanding that community and citizen science can lay a foundation for individual and community action is a challenge for youth (Ballard et al., 2017). Reinforcing these attitudes within community and citizen science programs will take deliberate design of supporting activities, such as this one, that can be easily delivered and adapted to a broad array of learners and learning settings. Educators in our study clearly valued the design of this method which provided many interdisciplinary engagement points across an entire year and the physical presence of a scientist. These created more opportunities to connect the youth science work to "the bigger picture" of environmental science and stewardship.

Continuing data collection for multiple years and communicating scientific results and scenario stories were the most common stewardship actions actually pursued by the youth groups (12 of 13 groups and 11 of 13 groups, respectively). Far fewer actually took actions from their scenario stories and pursued them; one group planted berry crops in their school garden and two preserved berries. Data collection and communicating science are more easily achieved by youth groups, with far less energy, time and financial resources required than to pursue a unique path through a self-determined action project. The ease in undertaking these actions, however, may not be the only explanation. In interviews and observational studies of two youth focused community and citizen science programs, Ballard et al. (2017) found that youth involved in community and citizen science projects tended to focus more on collecting high quality data according to the protocol, and developing a sense of expertise in a project than they did on the ways that they could use the experience as a foundation for personal or community change. This trend was also seen in our data, with the application of new data in scenarios stories was evident, and educators mentioning the data collection and application of the data more than the other thinking skills practiced through the activity. This is not surprising, as youth and educators spent the majority of their time during the project conducting data collection.

Motivation is a major driver of both participation in community and citizen science (Rotman et al., 2012; West and Pateman, 2016) and volunteering for environmental stewardship (Bruyere and Rappe, 2007; McDougle et al., 2011; Jacobson et al., 2012). The Winterberry program provided structural support and incentives for youth group participation in the community and citizen science aspects of the project, but did not actively facilitate or support in-depth stewardship planning or action beyond the hour long scenarios lesson. If this method were to be applied in settings without the structural constraints of classrooms and afterschool clubs, further study into the role of motivation and incentives, and intentional program design for supporting community and citizen science volunteers in stewardship action or policy advocacy would be recommended. In our study it was clear in both youth and educator datasets that the concern for the future of berries was present, and the actual pursuit of some actions beyond what was expected in the program was promising. However, the time and curriculum constraints in structured youth programs likely limits what can realistically be done even if motivation is high. Further, the time costs and motivations for implementing this method would shift if an educator chose to implement the activity themselves rather than having a citizen science program staff come in to deliver the lesson, as we did in our implementation.

The slight differences in youth who pictured themselves as agents of change in their scenario stories in rural settings and in group work are worth further analysis in future examination of this method. While most Alaskans in both rural and urban learning settings have experiences harvesting wild berries for food and recreation, the rural youth groups are surrounded by much smaller closer-knit communities where each individual has a role in the functioning of the community, and the cultural connection to berry resources is robust. This could influence the sense of agency in these youth. Group work also slightly increased the percentage of work samples that included the youth taking stewardship action compared to when they worked individually. This is despite the fact that all students participated in the deliberation as a group before working on their scenarios, and the time frame for the activity was kept constant across the groups. This may also be the result of youth working in groups feeling like they needed to be represented in the group work, while they had a different sense of ownership over the project when they worked on it as an individual. Educators also emphasized the effects of the group of students "making the project their own." Together these findings suggest that collaborative and social learning processes are important to this method, a point increasingly emphasized in the environmental education literature (Krasny and Tidball, 2009; Lebel et al., 2010; Bestelmeyer et al., 2015; Krasny, 2020).

To truly create community and citizen science for the future, we must engage youth in both the process of science and the process of using that science to guide us to a positive future. Our work supports the idea that pairing community and citizen science and scenarios development provides a concrete strategy for allowing youth to practice resilience thinking and imagining themselves as agents of change. It is a promising approach to help citizen science volunteers see how their data can inform planning and decision making to help create a positive future.

DATA AVAILABILITY STATEMENT

Only anonymized data summaries may be provided upon request and any data sharing will seek approval by the University of Alaska Fairbanks Institutional Review Board.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Alaska Fairbanks Institutional Review Board (1062412-5). Free prior and informed consent was obtained by adult educator participants and the legal guardian of the youth. Youth in the fourth grade or higher also provided their own signed informed consent to participate in the study. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

KS, DC, and CV contributed to the idea development, writing, and revision. KS and DS conceived and completed the analysis. All authors developed the methods and completed the field testing and data collection.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.695534/full#supplementary-material

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Low-Cost Citizen Science Effectively Monitors the Rapid Expansion of a Marine Invasive Species

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Citizen science and informed citizens have become fundamental in providing the first records and accounts about the expansion of numerous non-indigenous species. However, implementing a successful citizen science campaign can be expensive and particularly difficult for aquatic species. Here, we demonstrate how a low-cost citizen science campaign and its outreach plan in social and traditional media enabled to track the expansion of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 along the coast of Algarve (southern Portugal, Europe). We describe the outreach strategy and a cost-benefit analysis of the first year of the citizen science campaign. Social media platforms allowed us to reach a significant number of citizens (over 31,500 clicks in Facebook publications), while traditional media gave national visibility to the citizen science campaign and biological invasions. In only 1 year, we documented the spread of the invasive Atlantic blue crab across the entire 140 km of the Algarve coast with 166 valid observations referring to 1747 specimens, submitted by 62 citizen scientists. We spent 0 € on the citizen science campaign, but considering the time invested in the campaign the cost would have summed up to 3,751 €, while the total minimum cost for one scientist to go to the field and retrieve the equivalent information would have exceeded 11,000 €. We used free online tools of communication to obtain the records about the Atlantic blue crab, instead of a dedicated web platform or mobile app, and handled social media accounts ourselves, which saved us at least 18,815 €. The citizen science campaign revealed that the Atlantic blue crab is unequivocally established in southern Portugal and that females appear to exhibit summer migrations to coastal areas to spawn as in the native area. Overall, our low-cost citizen science campaign effectively documented the rapid spread of a marine invasive species while providing some insights into its ecology. Our strategy can be easily replicated and implemented elsewhere in the world to tackle the ever-growing problem of biological invasions while increasing the scientific literacy of local populations.

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1 INTRODUCTION

Environmental agencies and scientists struggle to implement efficient monitoring and management programs focused on biological invasions given its pervasive nature (Pyšek and Richardson, 2010; Courchamp et al., 2017), despite the increased global awareness about biological invasions and their impacts on the environment, biodiversity, and economy (Simberloff and Rejmánek, 2011; Dehnen-

Schmutz et al., 2018). Aquatic invasive species are particularly challenging to monitor and study due to the difficulty in accessing their habitats which increases costs while delaying the detection of new non-indigenous species (NIS) (Streftaris et al., 2005; Havel et al., 2015). The ability to detect a potentially invasive species during the initial phase of colonization is of the utmost importance, especially if control and mitigation measures are to be applied (Mehta et al., 2007; Simpson et al., 2009). With funding increasingly scarce towards long-term scientific projects and monitoring campaigns, scientists must consider every available tool to increase early detection rates, including citizen science (Gallo and Waitt, 2011; Azzurro et al., 2013; Morais et al., 2019; Encarnação et al., 2021; Pernat et al., 2021). Citizen science is defined as "any environmental and/or biological data collection and analysis, including data quality control, undertaken by members of the general public, as individuals or as organized groups of citizens, with the guidance and/or assistance of scientists towards solving environmental and/or community questions" (Encarnação et al., 2021). Additionally, reports from Local Ecological Knowledge experts—e.g., professional fishers, farmers, land managers, forest rangers—provide critical and timely insights into species distribution and behavior. For example, citizen scientists reported the first records of several marine NIS in the Mediterranean Sea (Azzurro et al., 2013, 2019; Zenetos et al., 2013), while fishers reported two new marine NIS in southern Portugal (Morais and Teodósio, 2016; Morais et al., 2019).

One of the fastest spreading marine invasive species across Europe is the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896, which has been listed as one of the 100 worst marine invasive species in the Mediterranean Sea (Streftaris and Zenetos, 2006; Nehring, 2011; Mancinelli et al., 2017). The species is native to the western Atlantic Ocean and found from the coast of Massachusetts in the United States to central Argentina (Alencar et al., 2013; Johnson 2015). It was recorded for the first time on the Atlantic coasts of Europe in 1900 and the Mediterranean Sea in 1935 (Bouvier, 1901; Nehring, 2011). Nowadays, several established populations exist in the North Sea (Belgium and Netherlands), Atlantic coasts of the Iberian Peninsula (Nehring, 2011; Morais et al., 2019; Vasconcelos et al., 2019), and across the Mediterranean Sea (Mancinelli et al., 2017; Taybi and Mabrouki, 2020). The contribution of citizen scientists in tracking the expansion of this species has been critical in the Mediterranean Sea. Fishers helped tracking the species' range expansion in Morocco (Taybi and Mabrouki, 2020), Algeria (Benabdi et al., 2019), Greece (Perdikaris et al., 2016), Albania (Beqiraj and Kashta, 2010), Italy (Suaria et al., 2017; Cerri et al., 2020), and Spain (Castejón and Guerao, 2013; González-Wangüemert and Pujol, 2016).

In Portugal, the first record of the Atlantic blue crab dates back to 1978 in the Tagus estuary (western coast) (Gaudêncio and Guerra, 1979), and the second record was made in 2009 in the Sado estuary just 30 km south of the Tagus estuary (Ribeiro and Veríssimo, 2014). This extended time lag indicates that the species failed to establish a population on the west coast of Portugal. However, on the southern coast of Portugal, the Algarve region, the establishment process was quite distinct. The first Atlantic blue crabs were collected in the Ria Formosa coastal lagoon in 2016, while reports from 2017 indicate that the species already occupied a 25 km stretch of the Guadiana estuary in the border between Portugal and Spain (Morais et al., 2019). Subsequent collections made between November 2018 and January 2019 in Ria Formosa and adjacent coastal areas have confirmed the presence and establishment of the species in the Eastern Algarve (Vasconcelos et al., 2019). Its presence in southern Portugal was hypothesized to be due to the expansion of neighbor populations from south Spain or even owing to a new introduction event (Morais et al., 2019; Vasconcelos et al., 2019).

The apparent fragmented distribution of the Atlantic blue crab in two ecosystems in southern Portugal (Morais et al., 2019), led us to hypothesize that this species has gone unnoticed by the scientific community, as it happens so often with other NIS (i.e., Azzurro et al., 2013; Morais and Teodósio 2016; Grason et al., 2018). This article focuses on the Atlantic blue crab as it became the most prominent marine invasive species in the Algarve, and aims to demonstrate the usefulness of citizen science to track the expansion of aquatic invasive species by 1) describing how we designed and implemented a citizen science campaign called NEMA (*Novas Espécies Marinhas do Algarve*—New Marine Species of the Algarve), and how it may serve as a model to other citizen science campaigns, 2) illustrating how effective a citizen science campaign can be in tracking the expansion of NIS using the Atlantic blue crab in Algarve as a model species, 3) elaborating a cost-benefit analysis to provide evidence on why we label NEMA as a low-cost citizen science campaign. This cost-benefit analysis includes an estimate of the range of savings that we achieved by using free online tools, such as social media, e-mail and biodiversity platforms, instead of custom-designed options, by handling social media ourselves, and lastly an estimate of the minimum costs for a scientist to retrieve the same information gathered by citizen scientists.

2 MATERIALS AND METHODS

2.1 Study Area

Southern Portugal (south-western Europe), which coincides with the Algarve region, is a Mediterranean climate region and the only arid or semiarid region in Portugal since annual rainfall is lower than 400 mm (Santos et al., 2010). Mean air temperatures range between 11°C in January and 27°C in August (World Weather Online 2021). The Algarve has four estuarine ecosystems, the Guadiana estuary and Ria Formosa lagoon in the eastern Algarve and the Arade estuary and Ria de Alvor lagoon in the western Algarve (**Figure 1**). The eastern zone of the south coast is mostly sandy, only interrupted by the Ria Formosa lagoon and its barrier islands, while the central and western zones of the south coast are characterized by limestone and sandstone rocky shores along with pocket sandy beaches, and cliffs towards the west coast (Moura et al., 2006). The continental platform also follows this typology, displaying a wider shelf (>40 km) and gentle slope to the east of Cape Santa Maria, while from here and towards Cape Saint Vincent (Sagres) the shelf is narrower (<15 km), the slope is steeper, and depths of 100 m can be reached within 10 km from the coast (Relvas and Barton, 2002; Garel

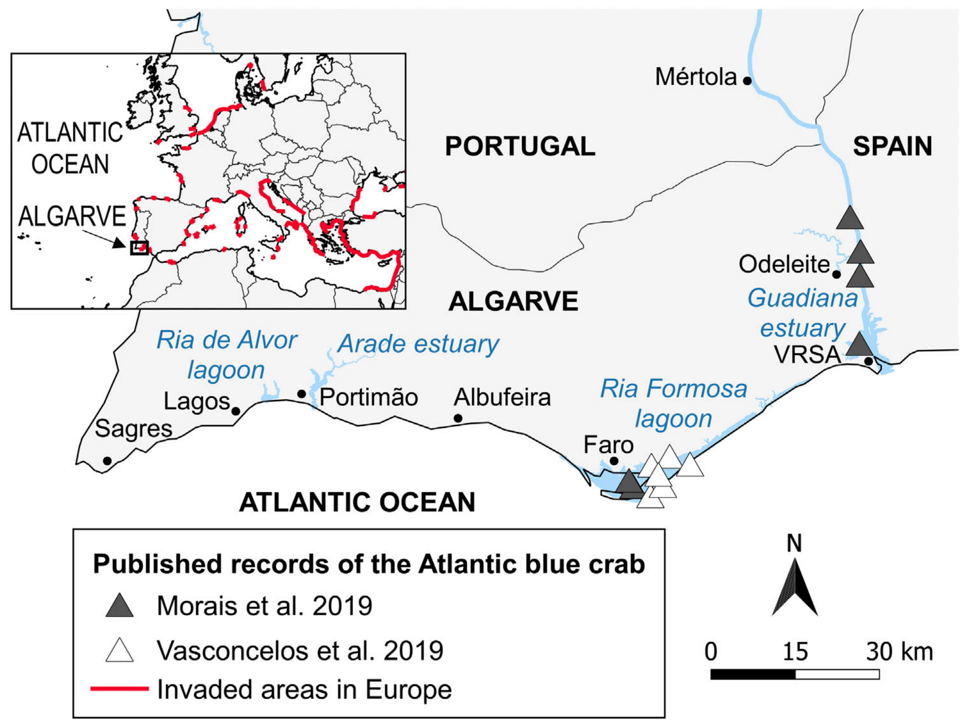

FIGURE 1 | Location of the Algarve region (southern Portugal, south-western Europe), and the areas with published records of the Atlantic blue crab across Europe and the Algarve, based on the available literature. Maps generated with QGIS 3.12 Bucuresti (QGIS.org, 2021).

et al., 2016). Mean sea surface temperature in the southern coast of the Algarve range between 15°C in January and February and above 20°C during summer, and it is increasing at a rate of +0.2°C decade^{-1} (Baptista et al., 2018).

2.2 Setting up a Low-Cost Citizen Science Campaign

NEMA is a citizen science campaign launched in April 2019 that focuses on the new aquatic species found along the Algarve coast, including estuaries and lagoons. We created a logo design that matches with the institutional image of the research centre (CCMAR—Centre of Marine Sciences) to increase credibility, facilitate outreach, and ultimately the number of submitted records (**Figure 2A**). The logo was designed for free by Dr. Sarita Camacho, as part of her graduation internship in Communication Design at the University of Algarve. The taxa chosen for the logo include some of the most emblematic new species in the Algarve and encompassing different taxonomic groups, as the invasive Atlantic blue crab *Callinectes sapidus* and bloom-forming jellyfish *Catostylus tagi*, or subtropical species like the ornate wrasse *Thalassoma pavo,* or the bearded fireworm *Hermodice carunculate* which may pose public health risks (Verdes et al., 2017; Encarnação et al., 2019). The website of NEMA (www.NEMAlgarve.com) was launched in May 2020, so it did not influence the outreach and outcomes of the first year of NEMA.

During NEMA's first year, we only used free web tools to promote the campaign and increase communication with citizen scientists. So, we created accounts on the main social media platforms—Facebook (link), Instagram (link), Twitter (link)—to promote NEMA and reach a high number of citizens in the shortest period possible. Additional communication channels were created, as a dedicated email account (nemalgarve@gmail.com) and a project page on BioDiversity4All (link)—a free biodiversity citizen science platform which is the Portuguese version of iNaturalist. NEMA's account on BioDiversity4All gathers the validated records received across all communication channels and are publicly available for consultation.

2.3 Promoting a Low-Cost Citizen Science Campaign

We actively promoted NEMA on social media platforms with information about its objectives, species of interest, and how citizens could participate in the campaign. We also made regular publications with the observations submitted by citizen scientists to acknowledge their contribution. To increase outreach, publications were often shared by our research centre (CCMAR) on their social media accounts. A poster with the species of interest (**Figure 2B**) was created and shared regularly on NEMA's social media accounts. Every month, from June to October 2019 and also January 2020, this poster was used as an outreach tool to engage with the public on several Facebook groups related to fishing and general ocean activities. On average, we reached out to 23 ± 6.3

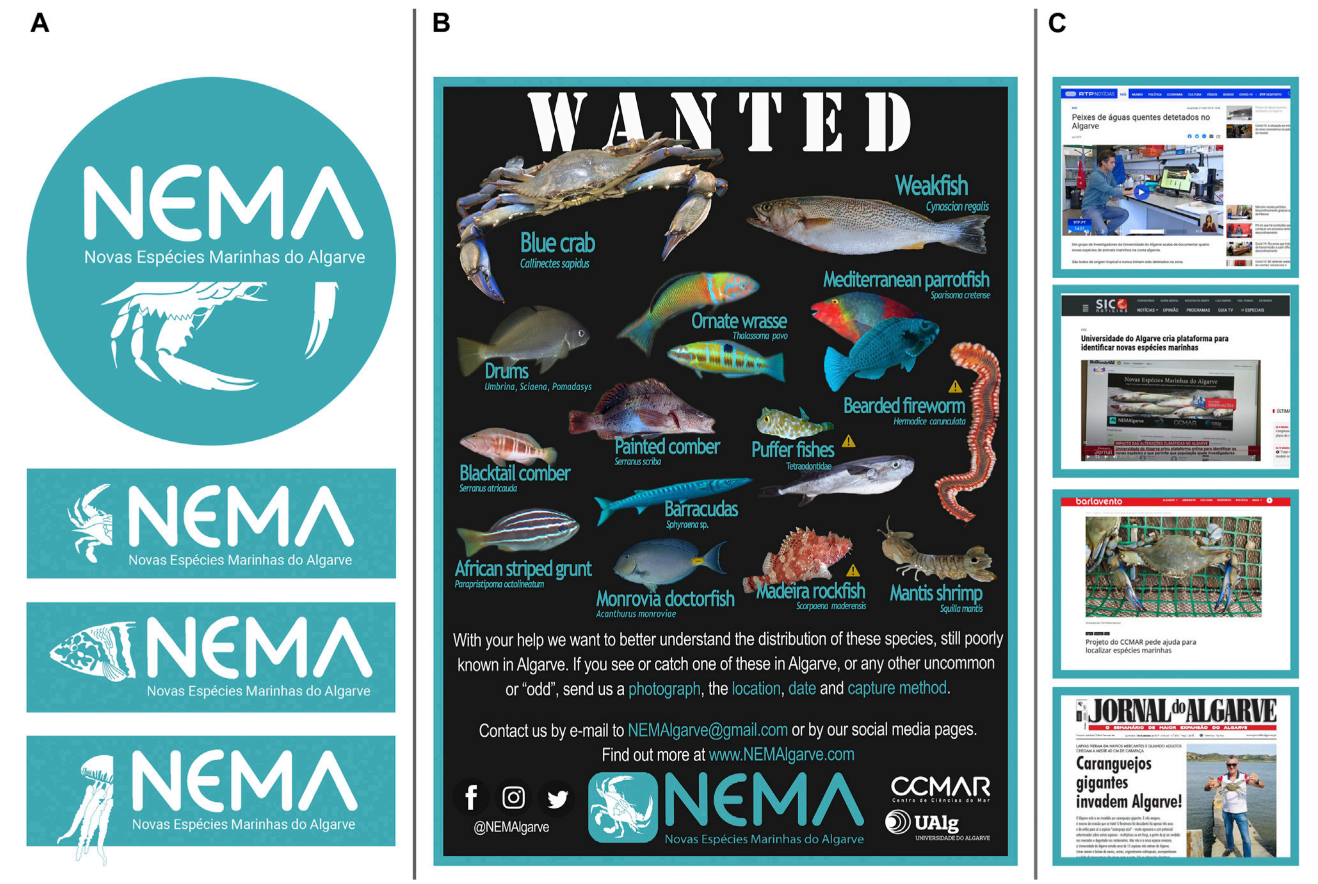

FIGURE 2 | Outreach materials and actions used to promote the NEMA citizen science campaign. **(A)** The NEMA institutional image includes a main logo, incorporating the Atlantic blue crab *Callinectes sapidus*, and complementary logos. **(B)** The NEMA "WANTED" poster used to promote the campaign on social media and call citizens for participation. **(C)** NEMA outreach actions resulted in tremendous media coverage, including interviews given to national television, and printed and online newspaper articles. For a complete list of media coverage, see **Supplementary Table S1** of the online Supplementary Material.

Facebook groups per month in this period. In most instances, we used the Portuguese version of the poster.

In May 2019, we issued a press release to local and national media about NEMA and its objectives. The visibility of NEMA on social media, in tandem with the press release, led to a growing interest from traditional media on the NEMA campaign, biological invasions, and species reaching southern Portugal owing to climate change (**Figure 2C**).

2.4 Data About Species Records

We asked citizen scientists to provide information about the species of interest and for five details about their observations: 1) a photograph of the specimen(s), 2) date, 3) location, 4) method of capture or observation, and, whenever possible, 5) the inclusion of an object to serve as a scale in the photograph. Only observations that included, at least, one photograph to allow the species identification, date of observation and a detailed location were considered valid and included in NEMA's database. The direct communication channels provided the opportunity to obtain all the details to validate observations and permission to add the observation to the database. Observations classified as "personal communications" refer to direct messages sent by friends or colleagues about an observation, or with a link or contact to the citizen scientist that made the observation.

Several observations pre-dating NEMA—before April 2019 and hereafter named pre-NEMA—were included in the present database. These were mostly made by two informed citizens, Mr. Gonçalves and Mr. Fernandes, that continued to provide records after the ones published by Morais et al. (2019). With the launch of NEMA, we were also able to reach several citizen scientists that already had older observations stored in digital devices and such records are also labelled as pre-NEMA.

Facebook was our most popular social media account, so we retrieved several metrics to assess the impact of social media outreach on the number of records. These metrics include the number of daily new Facebook followers, daily total impressions, and daily total consumers. Facebook defines daily total impressions as the number of times any content from the page or about the page entered a person's screen (e.g., posts, stories, check-ins, ads, and social information from people who interact with the page), while daily total consumers are the number of people who clicked on any of the account's content. We used linear regressions to assess the relationship between these metrics and the number of submitted observations.

2.5 Data Analyses

2.5.1 Documenting the Rapid Expansion of the Atlantic Blue Crab

First, we compared the number of validated Atlantic blue crab observations and specimens reported before and after the launch of NEMA to assess its impact. Second, we analyzed the number of validated observations and specimens according to distance to the eastern point of the Algarve (the mouth of the Guadiana estuary) to track the species' expansion along the coast. A third analysis considers the sex of the specimens which was only made when citizen scientists provided photographs that allowed such assessment or accurate descriptions of morphology. All other specimens were classified as unsexed. The classification of reproductive months for the present analysis—August, September, October—was based on the observations of ovigerous females (two in August 2019 and three in September 2019) and capture of females swimming at the surface at night (one in August 2019 and one in October 2019), which is associated with spawning events (Tankersley et al., 1998; Forward et al., 2005). Differences in the proportions of sexes (excluding unsexed) between reproductive periods (non-reproductive vs. reproductive) and ecosystems (coastal vs. estuarine) were evaluated with chi-square tests, using 2 × 2 contingency tables for each of the comparisons (de Sá 2007). Estuarine ecosystems, as opposed to coastal areas, refer to any body of water towards the inside of a river mouth, barrier island, or inlet. The non-parametric chi-square test was chosen because the assumptions of data normality (Shapiro-Wilk's test for normality) and homogeneity of variance (Levene's test) failed ($p < 0.01$), therefore disabling the use of a parametric analysis of variance test (de Sá 2007). Statistical analyses were done using R Studio version 1.4.1106 (RStudio Team, 2021).

We must highlight the significant contributions made by one informed citizen, Mr. Gonçalves, because he reported the first Atlantic blue crab captured in the Guadiana estuary in 2017 (Morais et al., 2019) and we kept a close collaboration since then. All the observations made by this fisherman from the Guadiana estuary since July 2018 were included in this database. These observations were analyzed separately because of their singularity—close collaboration, the high number of records, and small geographical range. Mr. Gonçalves uses mostly gillnets and traps on few occasions. Three independent gillnets, with an average size of 41 m length by 1.80 m heigh, were usually deployed during the afternoon and retrieved the following morning.

2.5.2 Cost-Benefit of a Low-Cost Citizen Science Campaign

We conducted a cost-benefit analysis of NEMA based on the costs of producing and running all the outreach platforms, and on retrieving the same Atlantic blue crab observations submitted by citizen scientists and informed citizens. To estimate the hypothetical costs we would have by running NEMA, we indexed the amount of time invested in each task to the daily stipend of a Ph.D. fellowship financed by the Foundation for Science and Technology (FCT, Portugal)—i.e., 51.20 € per workday, and compared it with service quotes from three companies.

This analysis was based on three components. The first component consisted in giving a cost to creating NEMA's communication channels, i.e., the campaign's accounts on BioDiversity4All, social media (Facebook, Instagram, and Twitter), and email. We spent seven work-days to create these platforms and then compared its cost, indexed to the FCT fellowship, with the cost of outsourcing the production of a website, mobile app, and create NEMA's social media accounts to obtain the records made by citizen scientists and informed citizens.

The second component consisted in giving a cost to handling NEMA's social media accounts, i.e., to create, publish, and follow-up each publication. We spent, on average, 1.5 h with each publication: 30 min for designing the publication, 20 min for publishing it, and 40 min for following up the publication, retrieving relevant information, or communicating with people that actively engaged with it. We compared the cost of the total number of publications, indexed to the FCT fellowship, with the cost of hiring a social media manager.

The third component consisted in calculating the expenses we would have in going to the field and collect the same information provided by citizen scientists or informed citizens. In a real situation, we would have needed to go to the field multiple times to increase the chances of making an observation, but due to the unforeseen nature of fieldwork, we can only calculate the minimum cost to retrieve the same record (one specimen or group of specimens) as the one made by a citizen scientist or informed citizen. The cost was calculated as the money spent by one scientist to travel to the observation site from the university campus, considering a car that spends 6 € 100 km^{-1} of gas, toll costs for a class 1 car (ViaLivre 2021), plus the daily stipend of the FCT fellowship. Distances were estimated with Google Maps, between the University campus in Faro (37.0428, −7.9735) and the closest road to the observation site (GPS positions available in **Supplementary Table S2**). For observations in the vicinities of Faro (between Albufeira and Tavira), no toll costs were included (n = 22). No costs related to boat renting and fuel, nor equipment depreciation were included in this analysis. The cost per trip was then divided by the number of specimens in each observation to obtain the cost per individual. Data is described by its range (minimum-maximum), the mean, and standard deviation was used as a measure of data dispersion. Lastly, this value was compared with the cost of retrieving the total number of observations through NEMA's communication channels, indexed to the FCT fellowship. We invested 10 min per observation, on average, to retrieve all the necessary parameters.

3 RESULTS

3.1 Media Coverage

During NEMA's first year, we focused mainly on social media outreach which resulted in traditional media becoming interested in the subject (**Figure 2C**). Between April 2019 and March 2020, two interviews were broadcasted on national television, fifteen online articles were published, two articles published on printed newspapers with one making cover page, and two interviews given to radio stations. The content of these news pieces included the discovery of NIS in Algarve and NEMA's citizen science campaign. The full list of articles and details about each one is available in **Supplementary Table S1**.

3.2 Impact of Social Media on Reports

Facebook was the social media platform most used by citizen scientists to contact NEMA—68% of all 84 validated observations of the Atlantic blue crab. NEMA's Facebook account received 57% of these observations (n = 48) and the other 11% (n = 9) were made through Facebook groups, or as a direct response to our explanatory publications in these groups (**Figure 3A**). No observations were reported through Instagram or Twitter. Observations uploaded on BioDiversity4All accounted for 12% of the records (n = 10), despite that most first contacts were also made through social media, followed by the upload of the observations on this platform by citizen scientists. NEMA's email received 7% of the observations (n = 6) and the remaining observations (13%, n = 11) were personal communications sent to us (**Figure 3A**).

The significant interest in NEMA's Facebook publications is shown by six sudden increases in the number of impressions (**Figure 3B**). The peak occurred on October 14, 2019, when these publications reached 40,905 people (daily total impressions) and generated 825 interactions (daily total consumers) (**Figure 3B**). The maximum number of interactions with NEMA's Facebook account was registered on December 21, 2019—2,839 interactions and 17,414 people reached (**Figure 3B**). During NEMA's first year, publications in Facebook reached a total of 669,417 people (impressions) and 31,565 interactions (consumers). We registered a positive relationship between the number of observations received with the daily total impressions (R^2 = 0.976), daily total consumers (R^2 = 0.973), and also with the number of Facebook followers (R^2 = 0.968). The number of observations reported on Facebook followed the increase in Facebook followers—2,163 by the end of March 2020 (**Figure 3C**). The main sources of new Facebook followers occurred after the publication of monthly explanatory posts on Facebook groups (**Figure 3D**), the coverage made by traditional media (dark arrows on **Figure 3B**), and publication of regular posts in NEMA's Facebook account.

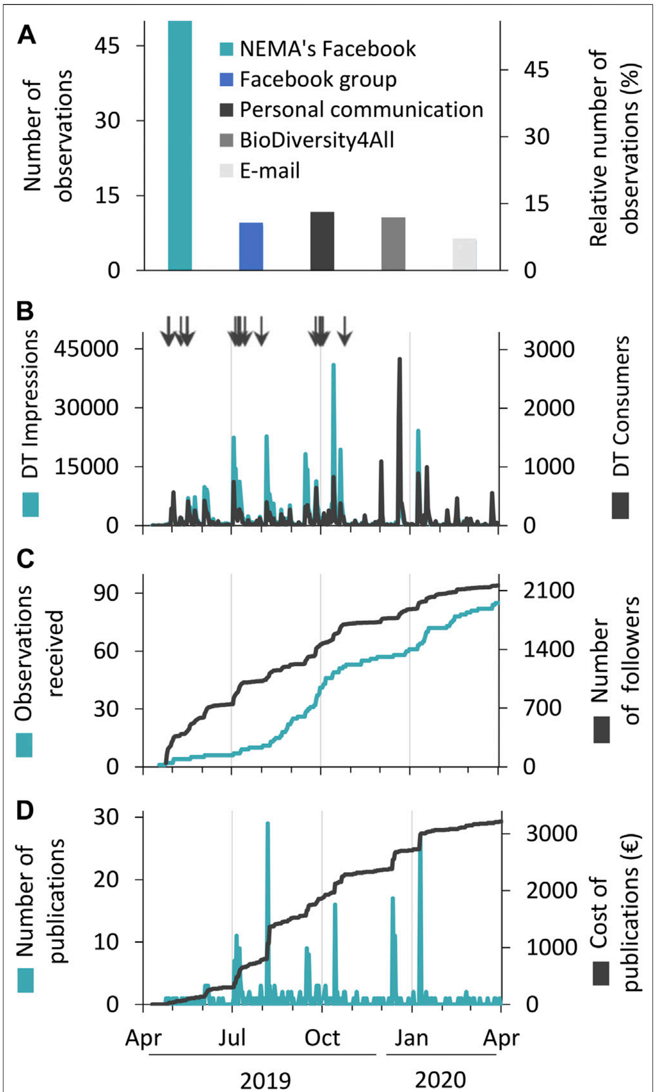

FIGURE 3 | (A) Contribution of each communication platform used by citizens to submit observations of the Atlantic blue crab to NEMA. **(B)** Facebook metrics between April 2019 and the end of March 2020, namely daily total (DT) impressions and daily total (DT) consumers. **(C)** The number of observations received in relation to the number of Facebook followers. **(D)** The total number of publications (including publications in NEMA's Facebook page and the monthly explanatory publications on Facebook groups related to fishing and ocean activities) and the estimated cost associated with such media handling. These estimates represent a minimum cost, as they were estimated based on the daily value of a Ph.D. fellowship of one scientist, and not a professional in social media management. Dark arrows indicate the date when newspaper and online articles and interviews were published or broadcasted by traditional media (full list in **Supplementary Table S1** of the online Supplementary Material). The observations made by Mr. Gonçalves (informed citizen) in the Guadiana estuary are not included in these figures.

3.3 Data on the Atlantic Blue Crab

Most Atlantic blue crab records were collected with a fishing gear (48.0%, n = 59), mostly with fishing nets (32.5%, n = 40), but also by hand (14.6%, n = 18) or found dead (18.7%, n = 23) (**Figure 4**). By the end of March 2020, NEMA's database, and therefore our sample size, included 166 valid observations from 1747 Atlantic blue crabs, submitted by 60 citizen scientists and two informed citizens (**Figure 5A**). Citizen scientists recruited by NEMA submitted 84 valid observations of 117 Atlantic blue crabs, while informed citizens contributed with 82

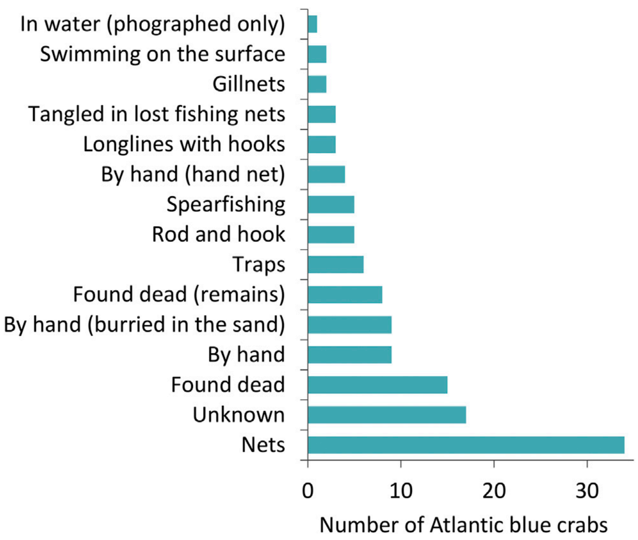

FIGURE 4 | Type of observation or method of capture reported by citizen scientists to NEMA about the Atlantic blue crab between April 2019 and the end of March 2020.

observations of 1,630 specimens. Observations registered before the launch of NEMA in April 2019, included observations mostly provided by the two informed citizens already mentioned (n = 23), while six citizen scientists provided seven observations (blue symbols in **Figure 5A**). These pre-NEMA observations were made in locations where the species had not been recorded before: one female in Ria de Alvor (May 15, 2018, record #20); one male in the eastern sector of the Ria Formosa near Tavira (March 4, 2019; record #12); one male in the coastal area off "Barrinha", an inlet of the Ria Formosa (March 27, 2019, record #4). The complete list of observations and NEMA's references are available in **Supplementary Table S2**.

The Guadiana estuary and the contributions made by Mr. Gonçalves represent a particular sub-set of records. This informed citizen alone reported 1,624 Atlantic blue crab specimens, all captured along a 12 km stretch of the middle Guadiana estuary, close to the village of Odeleite (**Figures 1, 5A**). Most specimens were males (58.8%, n = 955) and females only accounted for 6.0% (n = 97), while the remaining specimens were not sexed (35.2%, n = 572). Two months stood out—September 2019 (125 males, 6 females, 508 unsexed specimens) and March 2020 (456 males, 0 females). In 2019, the maximum daily catch was 105 specimens (September 17), and it reached 110 and 130 specimens in 2020 during two consecutive days, March 4 and March 5, respectively. No similar amount of daily catches were ever reported anywhere in Portugal. An additional 16 observations were made in this estuary by 11 citizen scientists about 21 specimens (**Supplementary Table S2**). Observations were mostly done in the middle and lower Guadiana estuary, but one dead specimen was found in Mértola at 70 km from the river mouth on October 6, 2019 (**Figure 5A**).

3.4 The Expansion of the Atlantic Blue Crab in the Algarve

Citizen scientists alone contributed with 77 valid observations about 109 Atlantic blue crabs, observed between April 2019 and March 2020—44.0% males (n = 48), 43.1% females (n = 47), 12.8% unsexed (n = 14) (**Figure 5A**). Observations made in estuarine ecosystems (Ria de Alvor, Arade estuary, Ria Formosa, and Guadiana estuary) accounted for 50.6% (n = 39) of the observations—61.7% males (n = 29), 34.0% females (n = 16), 4.3% unsexed (n = 2) (**Figures 5A, 6**). Observations made in coastal areas represented 49.4% (n = 38) of all records—30.6% males (n = 19), 50.0% females (n = 31), 19.4% unsexed (n = 12) (**Figures 5A, 6**). There were differences in the proportion of sexes between coastal and estuarine areas during the non-reproductive (p = 0.044) and reproductive periods (p = 0.065) (**Table 1**). In both cases, females were more frequent in coastal areas (31 specimens) than in estuarine ecosystems (16 specimens) (**Figure 6**).

In the first 3 months of NEMA (April-June 2019), only one Atlantic blue crab specimen was reported. Nonetheless, five specimens captured during July 2019 extended the known distribution westwards by over 50 km, from Faro to the Arade estuary in Portimão (**Figure 5A**). Two specimens captured in Ria de Alvor (one male, one female) further extended the distribution westwards by 8 km in August 2019. On September 19, 2019, one male specimen captured near the beach of Zavial further extended the western distribution limit by 23 km (**Figure 5A**).

Between August and November 2019, 16 observations (20 specimens: 7 males, 7 females, and 6 unsexed) confirmed the establishment of the Atlantic blue crab in the area between Albufeira and Alvor (green and orange symbols in **Figure 5A**). In the same period, between Faro and Vila Real de Santo António, 19 observations were made (21 specimens: 3 males, 13 females 4 unsexed) of which nine females have washed ashore in the beaches close to the mouth of the Guadiana estuary (**Figure 5A**). In August and September 2019, ovigerous females were reported (**Figure 5B**), one found dead in a beach close to the mouth of the Guadiana estuary (observation #34), two inside the Ria Formosa lagoon (observations #26 and #41), one in the Arade estuary (observation #17), and another one in the coastal zone of Portimão (observation #31). It is worth mentioning that two non-ovigerous females were captured at night while swimming at the surface on August 27, 2019, and October 2, 2019 (observations #22 and #42). In December 2019, a single observation (observation #66) reported one male and six females in the lower Guadiana estuary near Vila Real de Santo António, and one additional female was captured in the Sagres' harbor (observation #63). This last record extended the western distribution limit by another 4.5 km (**Figure 5**).

In January 2020, one fisherman made three observations on subtidal areas off Alvor and Lagos and mentioned that the Atlantic blue crab was a "frequent" bycatch. Two of these observations narrowed the gap of records made between Alvor and Sagres (**Figure 5A**). One of such observations reported 8 males and 3 females, all captured at night with a fishing net set near the Porto de Mós beach (Lagos, January 17, 2020) (**Figure 5C**). During the first 3 months of 2020, 10 observations confirmed the presence of the species in vicinities of Ria de Alvor and the Arade estuary (red

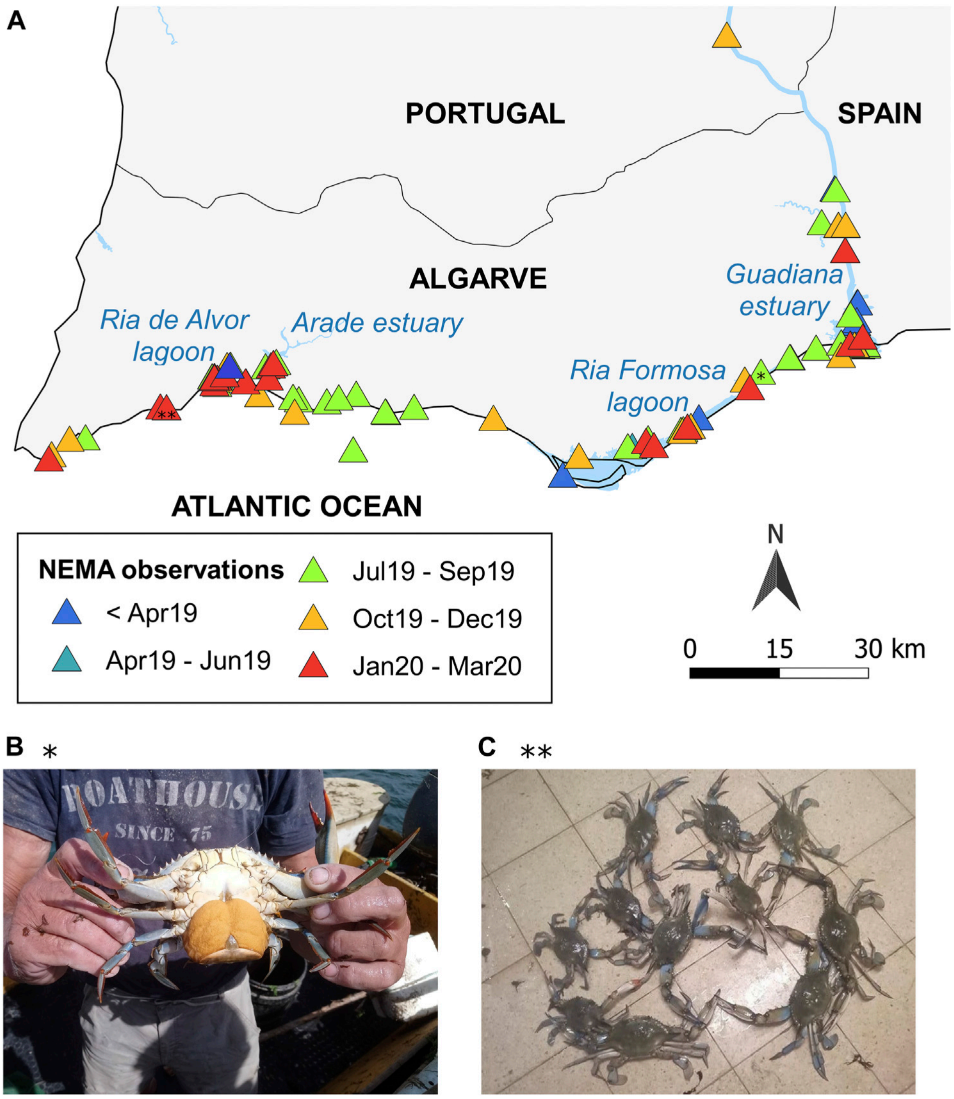

FIGURE 5 | (A) Observations documenting the expansion of the Atlantic blue crab from East to Western Algarve until the end of March 2020. Information submitted by informed citizens and citizen scientists to the NEMA citizen science campaign. Each icon represents an observation that may include more than one specimen. **(B)** An ovigerous Atlantic blue crab specimen collected in the Ria Formosa lagoon on September 20, 2019 (observation #41 submitted by D. Barragão). **(C)** Atlantic blue crabs collected off Lagos on January 17, 2019 (observation #70 submitted by V. Gomes). For a detailed list and description of each observation, please see **Supplementary Table S2** of the online Supplementary Material. Map generated with QGIS 3.12 Bucuresti (QGIS.org, 2021).

symbols in **Figure 5A**). The entire south coast of the Algarve was formally colonized by the Atlantic blue crab when a female specimen was recorded in the Mareta beach (Sagres) on March 3, 2020 (observation #86, westernmost red symbol in **Figure 5A**).

3.5 Cost-Benefit of a Low-Cost Citizen Science Campaign

Based on the number of hours we invested in launching and handling NEMA, the corresponding cost during its first year would have summed up to 3,751.47 € (**Figure 7**). Hiring the services of professionals to develop and handle all the digital platforms plus gathering the same number of records of the Atlantic blue crab in the field, would have cost between 29,815.58 € and 153,485.58 € (**Figure 7**).

The service quotes from three software developers to build a website and a smartphone app with basic features (i.e., submission of a photograph, location, date, and contact of the citizen scientist) were quite distinct—12,115 €, 55,350 €, and 81,180 €. The cost associated with the time invested in creating NEMA's social media accounts, e-mail, and project page on Biodiversity4All was only 358.40 € (**Figure 7**).

Between April 2019 and the end of March 2020, we made a total of 335 publications on Facebook—198 publications on

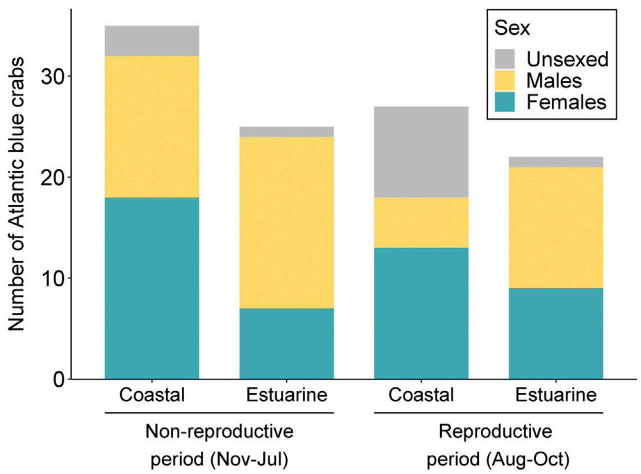

FIGURE 6 | Records of Atlantic blue crabs made in coastal or estuarine ecosystems of Algarve, according to the reproductive or non-reproductive period and their sex, submitted to NEMA by citizen scientists between April 2019 and the end of March 2020.

NEMA's Facebook account and 137 explanatory publications on Facebook groups (**Figure 3C**). Considering a value of 9.60 € per publication, the cost of media handling associated with these publications would correspond to a total of 3,216 € for this first year of NEMA (**Figures 3C**, **7**). For the same 355 publications, service quotes provided by professional social media managers were at 20 €, 50 €, and 183 € per publication, which would result in a total of 6,700 €, 16,750 €, and 61,305 € respectively (**Figure 7**).

The total cost for a NEMA scientist to go to the field and make the same 166 observations (1747 Atlantic blue crabs) would have reached 11,000.58€. The observations made before NEMA would sum up to a minimum of 2,015.61 €, while during the first year of NEMA, the total minimum cost would have been 8,984.96€—4,965.06 € for records made by citizen scientists and 4,019.90 € for records made by informed citizens. This represents an average minimum savings of 748.75 ± 505.77 € $month^{-1}$ during NEMA's first year. The maximum cost per individual was 75.73 € for the westernmost observation (record #86, Mareta beach, Sagres) and averaged 36.59 ± 28.05 € $individual^{-1}$ (**Figure 8**). The cost per individual was on average higher for observations provided by citizen scientists (6.59–75.73 € $individual^{-1}$, 58.99 ± 16.20 € $individual^{-1}$) than informed citizens (0.52–68.06 € $individual^{-1}$, 13.64 ± 16.73 € $individual^{-1}$) because observations made by informed citizens were mostly made in the Guadiana estuary and many individuals were reported in most observations (**Figure 8**). The minimum average cost per trip for a NEMA scientist to obtain the same record (one individual or several) as those made by citizen scientists was 64.35 ± 6.42 € $trip^{-1}$. This value was similar to the cost to obtain the same record as of informed citizens (68.23 ± 0.56 € $trip^{-1}$) since all these observations were done in the middle and lower Guadiana estuary (**Figure 8**). By investing our time in handling the digital communication channels to retrieve the 166 observations submitted by citizens scientists and informed citizens, we saved 177.07 € (**Figure 7**).

4 DISCUSSION

NEMA's citizen science campaign has demonstrated the value of citizen science in tracking biological invasions (Encarnação et al., 2021), while also showing the value of a set of low-cost tools that can be used to replicate this approach in other regions of the world. The high engagement of citizen scientists allowed to monitor the expansion of the invasive Atlantic blue crab along the Algarve coast, while providing relevant clues for future research hypotheses. These two aspects are detailed in the following sections.

4.1 Low-Cost Citizen Science With High Engagement

Detecting the presence of aquatic non-indigenous species after their introduction is extremely challenging and, in most cases, they only become noticed when an invasive status is reached (Mehta et al., 2007; Pyšek and Richardson, 2010). This has been tackled across the globe with rapid assessment surveys in artificial structures (Collin et al., 2015) or systematic surveys with fishing gears (Yamada et al., 2015; Poirier et al., 2017), but also using new technologies (e.g., eDNA analyses) that enhance the success of detecting NIS with low abundances (Rees et al., 2014). However, implementing eDNA monitoring programs is unfeasible in most regions due to the financial costs associated with this technology. In some cases, citizen sciences campaigns may mitigate the lack of intensive monitoring programs. For example, several successful citizen science campaigns have focused on crustaceans (e.g., Asian shore crab *Hemigrapsus sanguineus* and the European green crab *Carcinus maenas* (Delaney et al., 2008; Grason et al., 2018)), algae (e.g., *Caulerpa taxifolia* (Ellul et al., 2019)), or fish (e.g., lionfish *Pterois miles* (Azzurro et al., 2017; Giovos et al., 2018)). However, the running costs of citizen science

TABLE 1 | Chi-square test results, applied to 2 × 2 contingency tables, to assess differences in proportions of sexes between reproductive periods and ecosystems where Atlantic blue crabs were observed by citizen scientists.

	Value	df	*p* value
Coastal ecosystems (Non-reproductive vs. Reproductive)	1.247	1	0.264
Estuarine ecosystems (Non-reproductive vs. Reproductive)	0.916	1	0.339
Non-reproductive period (Coastal vs. Estuarine)	4.071	1	0.044
Reproductive period (Coastal vs. Estuarine)	3.399	1	0.065

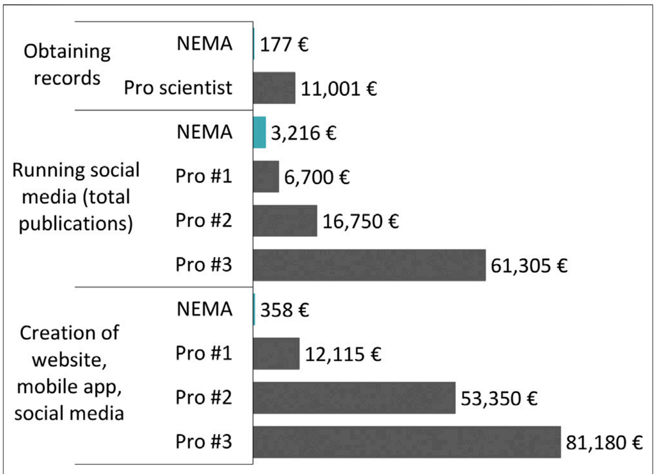

FIGURE 7 | Cost comparison between investing our time in running the citizen science campaign ourselves (NEMA); the minimum cost for a professional scientist to retrieve the same 166 observations submitted by citizen scientists; and three quotations provided for a social media manager to handle the same 335 publications made by NEMA's Facebook account, and for a professional to create all of NEMA's communication channels.

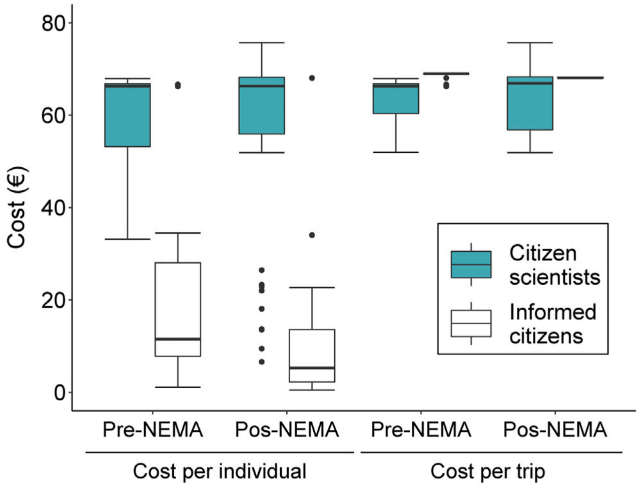

FIGURE 8 | Minimum cost for a scientist to obtain the same 166 observations (1747 Atlantic blue crabs) submitted by informed citizens and citizen scientists before (April 2018-March 2019) and during the NEMA campaign (April 2019-March 2020). These are minimum costs, as they only include transportation costs and the daily value of a Ph.D. fellowship of one scientist.

campaigns are unavailable to analyze and validate the cost-benefit of this approach.

During NEMA's first year, the campaign relied mostly on social media to communicate with potential citizen scientists. Social media provides a dual-communication channel with citizen scientists, i.e., allows promoting the project while providing updates on recent discoveries, increasing scientific literacy, and interact directly with citizen scientists. Direct communication with citizen scientists on Facebook provided valuable records about the Atlantic blue crab in the Algarve. However, asking citizen scientists to independently register their observations on BioDiversity4All citizen science platform was unsuccessful—only 11% of observations were registered on this platform by citizen scientists. Relying on free digital platforms (social media, e-mail, and citizen science platforms) meant running NEMA with no associated costs during its first year and save over 11,000€ for the total of 166 observations received (8,900€ for observations made only in the first year period). This is the minimum amount of money that we would need to obtain the exact same information on the field and with just one scientist. In comparison to the methods applied with NEMA's digital channels of communication, the corresponding cost in gathering these records would still be much lower (358 €).

Other successful citizen science projects relied on dedicated websites and/or smartphone apps (Gallo and Waitt, 2011; Azzurro et al., 2013, 2019; Zenetos et al., 2013; Marchante et al., 2017; Eritja et al., 2019). Such technologies are extremely costly to produce and maintain. Additionally, NEMA is being implemented as a long-term detection campaign, and such web platforms also require recurring annual fees. NEMA's approach to engage with citizen scientists mostly through online outreach is still a time-consuming methodology, that requires constant communication with participants and all the tasks associated with social media handling. If the time invested would result in a direct cost to create all the platforms and handling the social media pages ourselves, the correspondent cost during this first year of NEMA would have summed up to 3,574 €, which is still much lower than hiring professionals (18,815 €—142,485 €).

In Portugal, obtaining funding to establish long-term monitoring programs on aquatic invasive species is extremely unlikely. To overcome the idiosyncratic nature of Portuguese science funding, we opted for this low-cost approach which turned out to be extremely successful, while increasing the regional and national scientific and environmental literacy of the population. We will continue promoting NEMA for the foreseen future and we endorse the implementation of similar approaches in other regions of the world where scientific funding is scarce. Finally, biological invasion scientists should establish at least an "open communication channel" with citizens, even if not running a citizen science project, so that they can receive spontaneous contacts about new records while scouting social media and online forums (e.g., naturalists, fishers, hikers) for records of new NIS.

4.2 Tracking the Expansion of Invasive Aquatic Species

The best strategy to maximize participation and increase the number of records reported by citizen scientists is to establish multiple communication channels with scientists and research institutions (Encarnação et al., 2021). Despite following this recommendation, we acknowledge that our data may be biased since it likely engaged citizen scientists already concerned with environmental issues or with a strong interest in fishing (i.e., fishers and anglers). One informed citizen recorded 93.0% of the total 1747 Atlantic blue crabs reported to NEMA. Yet, the other 117 Atlantic blue crabs allowed to track the fast westward expansion of the species for over 90 km along the coast of the Algarve (**Figure 5A**). Furthermore, the number of reported individuals represents a 46-fold increase in comparison to data obtained during the 3 years prior to NEMA (Morais et al., 2019; Vasconcelos et al., 2019). NEMA also brought to light a record made in May 2018 at Alvor (**Figure 5A**, observation #20) which would have extended the known distribution in 65 km by the time the two scientific publications were made in 2019 (Morais et al., 2019; Vasconcelos et al., 2019).

Our study made clear that citizen scientists have different engagement levels, yet equally valuable to monitor biological invasions. Without a wide network of citizen scientists, we could not track the westward expansion of the Atlantic blue crab. Without an informed citizen from the Guadiana estuary (Mr. Gonçalves), we could not obtain precious information about the presence of the species in this estuary for an extended period of time. Therefore, all connections should be nourished. Developing short-training actions with citizen scientists will provide valuable long-term data while giving more autonomy for citizen scientists to gather data with different methodologies.

NEMA also obtained interesting details about the ecology of the Atlantic blue crab. Two females were reported to be swimming at the surface during the night close the coast, which is a typical behavior of ovigerous females that perform vertical migrations at night during the spawning periods (Tankersley et al., 1998; Aguilar et al., 2005; Forward et al., 2005). NEMA's data also showed that female Atlantic blue crabs were more common in coastal areas throughout the year, and not only during the reproductive period (August–October). Ovigerous females in coastal areas were only recorded once off Portimão, but the other three ovigerous individuals were found in the lower Arade estuary and Ria Formosa. The high mobility of Atlantic blue crabs and its fast adaptation to environmental conditions, namely salinity, are key factors for the selection of spawning areas (Forward et al., 2003; Aguilar et al., 2005), therefore spawning areas in Algarve seem to include both the lower section of estuaries and coastal areas.

5 CONCLUSION

Overall, we demonstrated that a low-cost citizen science campaign was able to track the rapid expansion of a marine invasive species. The model we implemented with NEMA can be easily replicated elsewhere in the world, while being adapted to the social context of each region or country and target species. NEMA tracked the establishment and expansion of the invasive Atlantic blue crab along the entire southern coast of Portugal, including multiple estuaries and lagoons. We also obtained interesting ecological information about the reproductive strategies of females which can be tested in future works. Finally, our work demonstrates that biological invasion scientists should include citizen science in their toolkit while nourishing the collaborations with informed citizens to detect, track, and study non-indigenous species.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JE had the idea to develop and implement NEMA; JE collected data during the NEMA campaign and VB collected data before NEMA; Data analyses were made by JE, PM, and MAT; JE and PM led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.752705/full#supplementary-material

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Translational Science Education Through Citizen Science

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Guided by the six elements of Translational Ecology (TE; i.e., decision-framing, collaboration, engagement, commitment, process, and communication), we showcase the first explicit example of a Translational Science Education (TSE) effort in the coastal redwood ecosystem of Humboldt County, CA. Using iNaturalist, a flexible and free citizen science/crowdsourcing app, we worked with students from grade school through college, and their teachers and community, to generate species lists for comparison among 19 school and non-profit locations spanning a range of urbanization. Importantly, this TSE effort resulted in both learning and data generation, highlighting the ability of a TSE framework to connect and benefit both students and researchers. Our data showed that, regardless of the age of the observers, holding organized BioBlitzes added substantially more species to local biodiversity lists than would have been generated without them. In support of current ecological theory, these data showed an urbanization gradient among sites, with rural sites containing fewer non-native species than urban ones. On the education side, qualitative assessments revealed students and educators remained engaged throughout the project. Future projects would also benefit by establishing quantifiable metrics for assessing student learning from project conception. Throughout the project, the fundamentals of TE were followed with repeated interactions and shared objectives developed over time within trusted community relationships. Such positive human interactions can lead new naturalists to think of themselves as champions of their local biodiversity (i.e., as land stewards). We anticipate that such newly empowered and locally expert naturalists will remain committed to land stewardship in perpetuity and that other scientists and educators are inspired to conduct similar work.

Keywords: Translational ecology, biodiversity, urbanization, citizen science, invasive species

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INTRODUCTION

Resource managers have long known that the conservation of natural resources is not sustainable without the inclusion of the local human community (Shafer 1997; Primack 2012). In addition, educators know that the next generation of scientists require hands-on, place-based experiential learning to develop a more in-depth understanding of core scientific concepts (Bransford et al., 2000; DeBoer 2000; Michael and Modell 2003; Lombardi 2007; Darling-Hammond et al., 2020). To address these complementary needs of resource management and hands on opportunities for students, we look to Translational Science Education (TSE, Sutherland et al., 2019), a recent outgrowth of the new field of Translational Ecology (TE) that was developed to provide a framework for improving coordination and collaboration between researchers and practitioners in order to produce actionable science (Brunson and Baker 2016; Enquist et al., 2017; Lawson et al., 2017). TE makes it possible to better address the enormous problems of the Anthropocene (e.g., climate change, habitat loss, invasive species, and pollution) while taking into account regionally specific ecological and social challenges and perspectives. It focuses limited resources on producing meaningful results through knowledge coproduction (Enquist et al., 2017; Hallett et al., 2017; Lawson et al., 2017). Taking TE one step farther, TSE "develops mutually beneficial partnerships between scientists and educators to help students" (Sutherland et al., 2019: 83) while also improving scientific knowledge.

This paper lays out the first explicit example of TSE, bringing the principles of TE together with the latest technology and the power of citizen science. Scientists are increasingly enlisting the public in providing information to advance scientific knowledge given limited resources (Bhattacharjee 2005; Bonney et al., 2009; Silvertown 2009; Wilson et al., 2017). With the proliferation of online platforms and applications supported by universities and other institutions (e.g., Project FeederWatch at Cornell University, iNaturalist at California Academy of Science), scientists and educators can simultaneously generate reliable scientific data and nurture public awareness and biophilia (Bonney et al., 2009; Dickinson et al., 2012; Theobald et al., 2015; Wilson et al., 2017). However, the process of establishing a citizen science project by an individual scientist, or a small group of public volunteers, remains daunting. Many scientists and educators have expressed concerns about the methods, technology, or data quality and the time-intensive nature of citizen science projects (Brewer 2002; Au 2007; McDonald and Songer 2008; Bell 2010; Bodmer 2010). For ecologists in particular, there is often a general distrust in the non-traditional generation of data, despite increasing evidence that citizen science can generate high quality ecological data with planning, effective citizen scientist training and guidance, and thorough data validation practices (Hunter et al., 2013; Callaghan and Gawlik 2015; van der Velde et al., 2017; Hochmair et al., 2020).

By including the community both physically and virtually to generate bigger, better, and more meaningful scientific data, this project models a TSE framework that can simultaneously benefit both students and educators. In this aspirational effort, students (i.e., the local citizen scientists) are the generators of knowledge. In doing so, students receive a more genuine and engaging educational experience that simultaneously generates knowledge necessary for solving an increasingly dire global conservation crisis. Meanwhile, the on-the-ground, proximate, active participation by local students can encourage budding naturalists and may even encourage conservation action and pro-environmental behavior (Crall et al., 2013; Toomey and Domroese 2013; McKinley et al., 2017).

Bringing educators, researchers, and students together into a mutually beneficial scientific relationship, the Tiny North Coast Places project provides a TSE case study focused on student groups surveying the biodiversity of species in a local ecosystem, in this case the Coastal Redwood ecosystem of California. The Tiny North Coast Places project employed the free crowdsourcing application iNaturalist, a citizen science platform hosted by the California Academy of Sciences that has nurtured a growing online naturalist community since 2011 (Bonney et al., 2016; Nugent 2018; O'Keeffe 2019). Using iNaturalist, students recorded organisms that they observed in their local community, mostly during organized BioBlitz surveys. A BioBlitz is a temporally bounded event during which individuals attempt to rapidly document as many species as possible in a particular geographic area to catalog biodiversity and species richness (Lundmark 2003; Baker et al., 2014). The data collected through iNaturalist can then be used to draw conclusions about the ability of citizen science to contribute to biodiversity knowledge and inform scientific questions. Through the Tiny North Coast Places project, we test the major principles of TE/TSE and show how a focus on these principles can improve the experience, the results, and the sustainability of experiential science education, while simultaneously generating high-quality, valuable data for science. Specifically, this case study is based on TSE principles.

Decision Framing

TSE aims to fulfill the goals of both scientific and educational participants through a citizen science project that is developed collaboratively. In this project, the desired outcomes of researchers and educators were complimentary, but not the same. As in many ecosystems around the world (Aronson et al., 2014; Elmqvist et al., 2016; Piano et al., 2020), there is likely a steep decline in native species diversity in the coastal redwood ecosystem with increasing urbanization, though to date this has been only sporadically documented (Noss 1999; Kalinowski and Johnson 2010; Welsh and Hodgson, 2013). A primary goal of the researchers participating in this project was to analyze how urbanization has impacted species diversity in coastal redwood systems. In this context, the researchers predicted that an urbanization gradient would be found in the coastal redwood system, with fewer introduced species in less populated and more forested survey sites. The researchers also aimed to investigate how the structure of our project would affect the data generated. In particular, they predicted that this project would contribute new species to the Humboldt County species lists, and that the use of short-term BioBlitzes would lead to significantly more observations and species being recorded above those generated by the one-year surveys for locations that did not utilize BioBlitzes.

On the education side, teachers in the Tiny North Coast Places project had the goal of engaging students in collecting scientifically-useful data as a way of meeting age-appropriate Next Generation Science Standards (National Research Council, 2012). Teachers framed the project within the NGSS framework in a manner suitable to the age of their students, with performance expectations set within each grade level. They then led students through separating and analyzing Tiny North Coast Places data using crosscutting concepts to illustrate core ideas in the life sciences that were appropriate to the grade level, with the goal of linking the scientific practice of data collection to educational outcomes (e.g., NGSS standard 2-LS4-1: Make observations of plants and animals to compare the diversity of life in different habitats). Educators at a partnering organization, the Sequoia Park Zoo, aimed to provide unique and fun experiences where participants could develop a closer connection to animals and the environment. In addition, they aimed to create programs that address cognitive, affective, and behavioral decision making, and to integrate local and global conservation topics into their educational programming. The zoo aimed to reach these goals in collaboration with local agencies, institutions, and organizations to collaborate on programs and activities, such as through participating in the Tiny North Coast Places project. Educators at the Sequoia Park Zoo organized BioBlitzes when school field trips visited the zoo, and worked with visiting students to safely explore the zoo and forest and discuss the impact non-native species can have on ecosystems.

Collaboration

As stated by Sutherland et al. (2019), TSE projects provide authentic learning experiences while furthering scientific knowledge. To accomplish this goal, the Tiny North Coast Places project was developed by one private citizen science champion (conservation biologist and Sequoia Park Zoo volunteer Elizabeth van Mantgem; see acknowledgements for a complete set of champions) in collaboration with the Humboldt County Office of Education staff, teachers, and volunteer parents, with support from the Sequoia Park Zoo (Guest Services and Education Curator Christine Noel, Zoo Director Gretchen Ziegler) and funding from the locally-based Save the Redwoods League (Deborah Zierten, Education & Interpretation Manager). While the private citizen science champion developed the original idea for the project, educators took the idea for the project into their classrooms and made it their own, integrating it into their established lesson plans to help reach NGSS curriculum standards. The use of iNaturalist maintained consistency in the project by ensuring that all collaborators were connected and all data were collated, despite the variance in the frequency with which data were collected and differences in the lessons taught by teachers.

Engagement

TSE calls for educators to be genuinely engaged in research, and for researchers to be genuinely engaged in education. This project helped the students and staff in the Humboldt County School community engage with nature and scientific research by learning how to find, photo-observe, and appreciate plants and animals as modern-day hunter-gatherers. Students collected valuable biodiversity data as they learned about the species found commonly at their schools and connected with nature. Throughout the process, students were engaged in learning not just scientific concepts, but also how to be scientists in accordance with NGSS curriculum. These standards focus on three-dimensional learning by integrating practices used in scientific inquiry (e.g. behaviors, methods), crosscutting concepts that can be applied across scientific discipline (e.g., identifying patterns, energy), and core disciplinary ideas (e.g., ecosystems, heredity in the life sciences; National Research Council, 2012; Bybee 2013). Teachers ensured that students were engaged with and learning through the Tiny North Coast Places project by outlining the project within the NGSS framework and presenting the iNaturalist photo-observations as a game. Student teams within classes were encouraged to "compete" against other teams at their own and other schools to see who could find the most species as a way to increase engagement. A primary objective was to give participants a deep appreciation for local biodiversity and conservation and a deeper understanding of how to be scientists.

Commitment

Much like commitment from researchers is key to a successful translational ecology process, TSE requires a sense of responsibility and commitment to continued engagement from educators, researchers, and students toward building and maintaining productive citizen science relationships. Educators and students pledged to participate in the Tiny North Coast Places project throughout the year, while researchers were responsible for analyzing and publishing the collected data so the results could be known by all participants. Key champions within the Humboldt County school system were enlisted to ensure continued commitment to the Tiny North Coast Places project. The project aimed to help give students and staff the confidence to make scientific observations elsewhere, after taking the time to become engaged with the process of citizen science in this project. This confidence might encourage them to try deeper, more complicated citizen science projects (i.e. projects with effort data and protocols, like Project Feederwatch or CA Phenology Project) after they become competent with the introductory, iNaturalist observation data collection methodology.

Process

This project aimed to practice TSE effectively through frequent interaction and knowledge exchange, with methods updated as the project moved forward to be responsive to the needs of all participants. As previously mentioned, this project used the iNaturalist platform as a simple method for collecting observations that allowed all participants to contribute and look at the collected data. It leaned on the formal relationship of teachers to students and zoo groups to increase the chances of obtaining high-quality photo observations collected at regular intervals, and to ensure continued student engagement throughout the project.

Communication

Authenticity is the difference between traditional experiential learning and TSE. The integration of researchers into the curriculum facilitates better dialogue and more effective learning experiences (Sutherland et al., 2019). In the case of a citizen science project, iNaturalist provides a versatile and accessible platform by allowing the community of naturalists to directly question and inform the experts among them of any new, local wildlife eccentricities and changes. These observations can then be immediately weighed against more familiar natural histories of the organisms they are observing. Ideally, the newer naturalists in the community actually see some of the impact of their contributions to science through supportive dialogue, updated phenology graphs, and altered range maps. Communication between the initiator of the project, citizen science champion Elizabeth van Mantgem, educators, and students was maintained throughout the project to encourage student citizen scientists to remain engaged. Ms. van Mantgem worked with students on a regular basis to present the Tiny North Coast Places project as a game, where they were competing to find the most species. Teachers regularly encouraged their students to participate, and remained in contact with Ms. van Mantgem throughout the project.

Here we present results highlighting the ability to answer scientific research questions using data generated in a TSE framework, and show how the structure of a project can shape the results generated. These analyses can then be used by other researchers to better plan and structure their own TSE projects.

METHODS

Location

The Tiny North Coast Places project was conducted primarily in Humboldt County, California, United States (40.7450oN, 123.8695oW), which is situated both inside and outside of the current Coastal Redwood (*Sequoia sempervirens* [(Lamb. Ex D. Don) Endl.]) range boundary (Noss 1999). Humboldt County is a densely forested but sparsely populated (approximately 132,000 people), 1.5 million acre California county with a predominantly Mediterranean climate of cool wet winters and warmer, drier summers.

Population and Partners

This project involved the partnership of the Humboldt County Office of Education, Humboldt State University, College of the Redwoods, Sequoia Park Zoo, Freshwater Farms Reserve, and Humboldt Coastal Nature Center, with funding from the Save the Redwoods League. The Humboldt County Office of Education supports over 18,000 students of diverse ethnicities on 31 different school district properties (80+ school parcels) totaling about 4,052 square miles of land. These properties are distributed across the entire county and include important plant and animal populations outside, but not excluded from, protected Coastal Redwood land boundaries. A total of 14 K-12 schools participated in the Tiny North Coast Places project with participants ranging from elementary to high school aged. Humboldt State University is a public university of over 6,000 students situated in a rural area at the edge of coastal redwood forest, while the College of the Redwoods is a public community college similarly located in a rural area near coastal redwood forest. The Sequoia Park Zoo, Freshwater Farms Reserve (a restored wetland reserve), and the Humboldt Coastal Nature Center are all non-profit or city-run organizations. After data collection, four research scientists joined the project to analyze the data and write up the results.

Program Description

The program was carried out during the 2017–2018 academic year using the iNaturalist app, an online platform to which users upload observations of organisms in their surroundings. These observations can be photographs of organisms, tracks, nests, etc, with information about the time and georeference of the photograph also uploaded if it is available. Observations are then available for other fellow naturalists to view and identify, with observations deemed either “Needs ID” or “Research Grade” to provide information about the reliability of the data. Observations with a photograph or audio record and at least two independent agreeing verifications are considered Research Grade (RG). Data on the iNaturalist app can then be used in scientific research to draw conclusions about species distributions, diversity, and more. iNaturalist allows users to create “Projects”, in which observations for specific efforts such as citizen science projects can be collated in one directory; multiple projects can even be linked together under the heading of an overall “Umbrella Project”. Similarly, the “Places” feature of iNaturalist allows users to specify geographic regions in which data will be collected for a project.

For the Tiny North Coast Places project, we created a one-year Collection Project on iNaturalist for each participating school or nonprofit to which participants could upload their species observations. All of these Collection Projects were linked under the Tiny North Coast Places Umbrella Project, which allowed for species comparisons between groups. To mimic plot-based quadrat sampling, we used the iNaturalist Places feature to create tiny virtual ‘plots’ in Humboldt County in which to monitor species diversity and changes over time. We created one virtual plot encompassing the school grounds for each of the 14 participating Humboldt County schools, as well as for each of the two participating universities and three non-profit land organizations, giving us a total of 19 plots. The data collected in each plot could therefore be assigned to its corresponding Collection Project, and analyzed within the context of the entire Tiny North Coast Places dataset.

During the project year(s), a group of staff, students, and other community members for each location was encouraged and coached to try photo-collecting plants, fungi, insects, animals, and signs (e.g., tracks, scat, burrows, etc.) using the iNaturalist platform. Where there was interest, shorter-term site-tailored iNaturalist BioBlitz events were created to enhance both the fun and the abundance of data collection (see **Table 1**, column 5). Most of these BioBlitzes were one-to three-hour-long events with the exception of the semester-long BioBlitz conducted by Humboldt State University.

Finally, to encourage participation, schools that agreed to facilitate BioBlitzes at their own school sites were offered a free field trip to the zoo for up to 60 students, during which they could help monitor the Sequoia Park’s biodiversity via an iNaturalist BioBlitz Collection Project, then picnic and visit the *ex situ* animal collections on the zoo grounds.

TABLE 1 | Summary information for each site involved in the Tiny North Coast Places project. Information on the observer characteristics, land use characteristics, and summary data are shown.

Site	Year	Education grades	# Observers	BioBlitz	Zoo field trip	Disturbance	Population density	Borders forest	# Observations	# Species	# Introduced species
1	2017	1–5	11	Yes	No	Disturbed	High	No	278	139	37
2	2017	>12	45	Yes	No	Natural	Low	Yes	345	178	16
2	2018	>12	90	Yes	No	Natural	Low	Yes	687	309	31
3[a]	2018	7–12	1	No	No	Disturbed	High	No	1	1	1
4	2018	7–12	28	No	No	Disturbed	High	No	77	59	11
5	2018	NA	26	Yes	No	Disturbed	Low	No	126	94	21
6	2018	1–5	9	Yes	Yes	Disturbed	Low	No	103	68	21
7[a]	2018	7–12	4	No	No	Natural	Low	Yes	13	11	4
8	2018	NA	50	Yes	No	Natural	Low	No	229	111	10
9	2018	>12	171	Yes	No	Disturbed	High	Yes	1,281	668	76
10	2018	1–8	8	No	No	Disturbed	High	No	96	78	21
11[a]	2018	1–5	1	No	Yes	Natural	Low	Yes	15	11	1
12	2018	1–5	4	Yes	Yes	Natural	Low	Yes	75	58	5
13	2018	1–5	9	Yes	Yes	Disturbed	Low	No	342	173	43
14	2018	9–12	8	No	Yes	Disturbed	High	No	33	30	9
15	2018	1–5	7	Yes	Yes	Natural	High	Yes	140	74	6
16	2018	NA	65	No	No	Disturbed	High	Yes	1,313	284	33
17	2018	1–5	35	Yes	Yes	Natural	Low	Yes	533	262	39
18	2018	1–5	15	No	No	Disturbed	High	No	62	49	9
19[a]	2018	6–8	3	No	Yes	Disturbed	High	Yes	7	7	1

[a]*Denotes a site with 15 or fewer total observations which was therefore not included in statistical analyses.*

Data Retrieval and Analysis

The complete set of observations and identifications was retrieved for each virtual plot on May 12, 2019—excluding the combined Sequoia Park Zoo site which was retrieved on July 1, 2019—as a static snapshot of the dataset, to control for the ongoing updating of species identifications on iNaturalist (Ueda 2021; Young et al., 2021). For each site, summaries of the full dataset were extracted for analysis, including the number of observers, the number of observations, the number of species, and the number of species categorized as 'introduced' by iNaturalist (**Table 1**). Information about observer characteristics were recorded for each site, including the educational level of the observing group, if a site conducted an official BioBlitz, if the group took a field trip to the zoo, and the year observations took place. Land use within each location was also recorded at each site by the project organizer (EFvM) using binary variables for level of disturbance (high or low, corresponding to developed urban or undeveloped rural areas respectively), population density (high or low, again corresponding to urban or rural locations), and proximity to forest (overlapping or not overlapping with redwood forests, with one or more miles separating location and redwood forest). Sites with 15 or fewer total observations were excluded from further analyses due to the small sample size.

To determine the effects of urbanization on species diversity and the number of introduced species, we analyzed the impact of land use characteristics on four metrics of taxonomic diversity. The Shannon diversity index, Shannon evenness index, number of species observed, and number of introduced species observed were calculated for each of the sites using only research grade observations to ensure data trustworthiness. We used each diversity measure as the response variable in a separate generalized linear model using a Gaussian distribution for both Shannon indices and a negative binomial distribution for both species models. We used a Gaussian distribution for the models of Shannon diversity and evenness as Shapiro-Wilk tests indicated that neither of the metrics derived from the research-grade dataset nor the total dataset deviated significantly from a normal distribution (Shannon diversity: $p = 0.62$ total, $p = 0.36$ Research Grade; Evenness: $p = 0.06$ total, $p = 0.17$ Research Grade). We used a negative binomial distribution for both species models as they consisted of overdispersed count data. The binary land use variables of disturbance, forest relationship, and population density were considered as fixed factors in each model. Model selection for each response variable was performed by starting from a null model and adding fixed factors to increase complexity; the null model contained no fixed factors. The final selected model for each response variable was chosen based on having the lowest Akaike Information Criterion (AICc), and was then analyzed using ANOVA.

To determine the effects of observer characteristics on the amount of data collected, we used generalized linear models to analyze the response variables of: number of total observations, number of research grade observations, total number of species observed, number of research grade species observed, number of total observations of introduced species, number of research grade observations of introduced species, total number of introduced species observed, and number of research grade introduced species observed. As these response variables were composed of overdispersed counts, we used a negative binomial distribution in the generalized linear

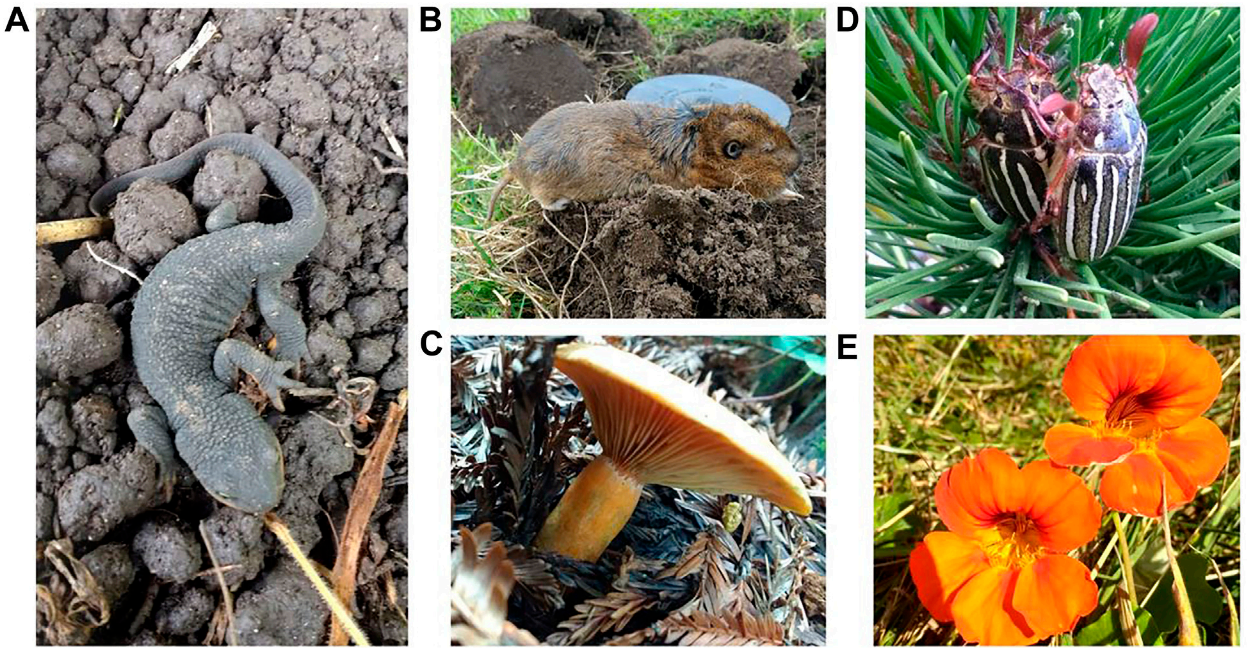

FIGURE 1 | Representative observations from the Tiny North Coast Places project on iNaturalist. **(A)**: rough-skinned newt (*Taricha granulosa*); **(B)**: Botta's pocket gopher (*Thomomys bottae*); **(C)**: saffron milkcap (*Lactarius deliciosus*); **(D)**: ten-lined June beetle (*Polyphylla decemlineata*); **(E)**: Nasturtium (*Tropaeolum majus*). Images taken by E. F. van Mantgem.

models. The observer characteristics of education level, BioBlitz participation, zoo trip participation, and number of observers were used as fixed factors in each model. Similarly, to determine the effects of observer characteristics on the type of data collected, we used generalized linear models to analyze the response variables of: percentage of observations that were plants, percentage of observation that were birds, and percentage of observations that were not in one of those two groups. As our response variables consisted of percentages, we used a binomial distribution with a logit link function in our generalized linear models. The observer characteristics of education level, BioBlitz participation, zoo trip participation, and number of observers were considered as fixed factors in each model. Model selection based on AICc was used to select all final models as previously described, after which final models were analyzed using ANOVA.

Because we were specifically interested in the usefulness of performing a BioBlitz on the ability to detect biodiversity and increase observations, we conducted t-tests analyzing the effect of participating in a BioBlitz on the subsequent Shannon diversity index, number of research grade observations collected, and number of research grade species detected.

Finally, we fitted species accumulation curves on the full dataset to assess whether the asymptote for species detection was approached for the project. We fit separate accumulation curves based on the number of observers, number of sampling days, and number of sites.

All analyses were conducted in R (version 4.0.2; R Core Team 2016) with RStudio (version 1.3.959; RStudio Team 2020) using the packages vegan (version 2.5–6; Oksanen et al., 2019), MASS (version 7.3–51.6; Venables and Ripley 2002), and lubridate (version 1.7.9; Grolemund and Wickham 2011), and figures were generated using ggplot2 (version 3.3.2; Wickham 2016).

RESULTS

Qualitative Findings

Both common and uncommon Redwood Coast species were photo-observed and mapped by new citizen scientists of all ages and levels of expertise throughout the year.]Because the iNaturalist platform requires standardized metadata (e.g. location, date, and photo) in order to be included in the potential research data set, all included data were collected in a consistent format regardless of participant age or location.

Across all sites, a total of 5,306 observations were collected; 2,177 (41.02%) of these were Research Grade (RG). These RG observations represented 529 unique species (**Figure 1**; **Supplementary Table S1**). Of the total number of species (2,550) that have been observed and recorded as RG in Humboldt County on iNaturalist, 21.25% of those species were observed in this project. Our observations also added new species to the iNaturalist dataset for the study area, such as the common shiny woodlouse (*Oniscus asellus* [Linnaeus]; RG), the granulated

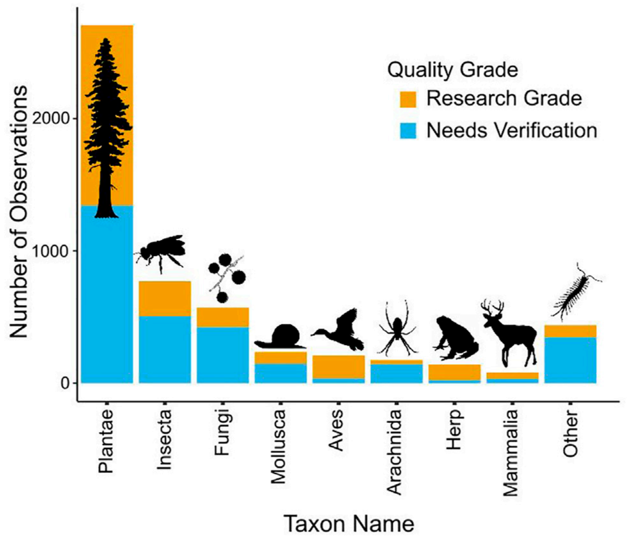

FIGURE 2 | Observations (Research Grade in brown) by taxa recorded over the course of the Tiny North Coast Places project.

ground beetle (*Carabus granulatus* [Linnaeus]; RG), the collared false darkling beetle (*Phryganophilus collaris* [LeConte]; RG), and the variegated yellow archangel (*Lamium galeobdolon argentatum* [(Smejkal) J Duvign.]; RG), an invasive wildflower.

Observations were collected during every month of the year, with a high of 1,089 observations collected in May and a low of 156 observations collected in January. Additionally, new users submitted observations to iNaturalist each month, indicating growing participation over time. Observations were collected on 375 days across 2017 and 2018, with an average of 15.35 observations collected on observation days. When excluding sites with unusually low participation (15 or fewer total observations recorded), the mean number of observations by site was 357.5 ± 102.34 (mean ± standard error) with a minimum of 33 observation at Redwood Coast Montessori High School and a maximum of 1,313 observations at Sequoia Park Zoo. The mean number of species observed at each site and labeled as RG was 62.06 ± 13.83. Of the observations, the most represented Kingdom in both 'research grade' and 'needs verification' observations was plants, followed by insects and fungi (**Figure 2**).

TSE Citizen Science as a Research Tool

As a representative example of how citizen science data can be used in the TSE context to answer scientific research questions, we investigated how urbanization affected species diversity and the number of introduced species within Humboldt County. After model selection, the most predictive generalized linear models for the effect of binary land use characteristics on Shannon diversity index and Shannon evenness contained only the fixed factor of relationship to forest. Sites that overlapped with redwood forests had significantly higher Shannon diversity indexes ($X^2 = 4.63$, $DF = 1$, $p = 0.032$), but significantly lower evenness ($X^2 = 4.92$, $DF = 1$, $p = 0.027$) than did sites that did not overlap with redwood forests (**Figures 3A,B**).

The most predictive model for the number of species recorded as RG included only the relationship to forest, with more species seen in sites that included redwood forests ($X^2 = 12.24$, $DF = 1$, $p = 0.00047$; **Figure 3C**). The final model for the number of RG introduced species recorded included the significant fixed effects of relationship to forest ($X^2 = 4.18$, $DF = 1$, $p = 0.041$) and disturbance ($X^2 = 9.22$, $DF = 1$, $p = 0.0024$). Surprisingly, we saw a trend towards higher numbers of introduced species in areas overlapping with forest ($p = 0.055$). As expected, more introduced species were recorded in areas with higher levels of disturbance ($p = 0.0040$; **Figure 3D**).

Observer Effects on Project Outputs

To provide insight into how the structure of a project can shape the resulting data collection, we first present results on the effect of observer characteristics on the amount and type of data collected. Next, we present findings on the specific impact of conducting a BioBlitz on diversity detection and observations. Finally, we present results on the accumulation of species detection over sampling effort.

Education level alone was the best predictor for amounts of all types of data collected, excluding the number of introduced species recorded as RG, for which the number of observations alone was the best predictor. As education level increased, the number of total ($X^2 = 26.23$, $DF = 4$, $p < 0.0001$) and RG observations ($X^2 = 27.67$, $DF = 4$, $p < 0.0001$; **Figure 4A**) recorded significantly increased as well. A similar pattern was seen when looking at the number of species recorded: the number of total ($X^2 = 26.31$, $DF = 4$, $p < 0.0001$) and RG species ($X^2 = 31.69$, $DF = 4$, $p = 2.21\text{e-}6$; **Figure 4B**) recorded both increased with education level. We found no effect of education level on the number of observations of introduced organisms for both total ($X^2 = 6.24$, $DF = 4$, $p = 0.18$) and RG observations ($X^2 = 4.72$, $DF = 4$, $p = 0.32$). Education also had no effect on the total number of introduced species that were recorded ($X^2 = 5.45$, $DF = 4$, $p = 0.25$). Unlike the other metrics for amount of data collected, the total number of introduced species recorded as RG increased with the number of observers participating ($X^2 = 5.83$, $DF = 4$, $p = 0.016$; **Figure 4C**). However, the significant relationships between education level and the observation metrics described here should be interpreted with caution, as the significant positive increase associated with increased education was driven solely by the observations at Humboldt State University; observations between K-12 education levels did not differ from each other.

The effect of observer characteristics differed by taxa. We found that the percentage of RG observations that were of plants was significantly influenced by observer education level ($X^2 = 80.05$, $DF = 4$, $p < 0.0001$) and the number of observers ($X^2 = 24.09$, $DF = 4$, $p < 0.0001$). In particular, we found that the proportion of observations at a site that were of plants decreased as either the number of observers or education level increased (**Figures 5A,B**). Similarly, the percentage of RG observations of

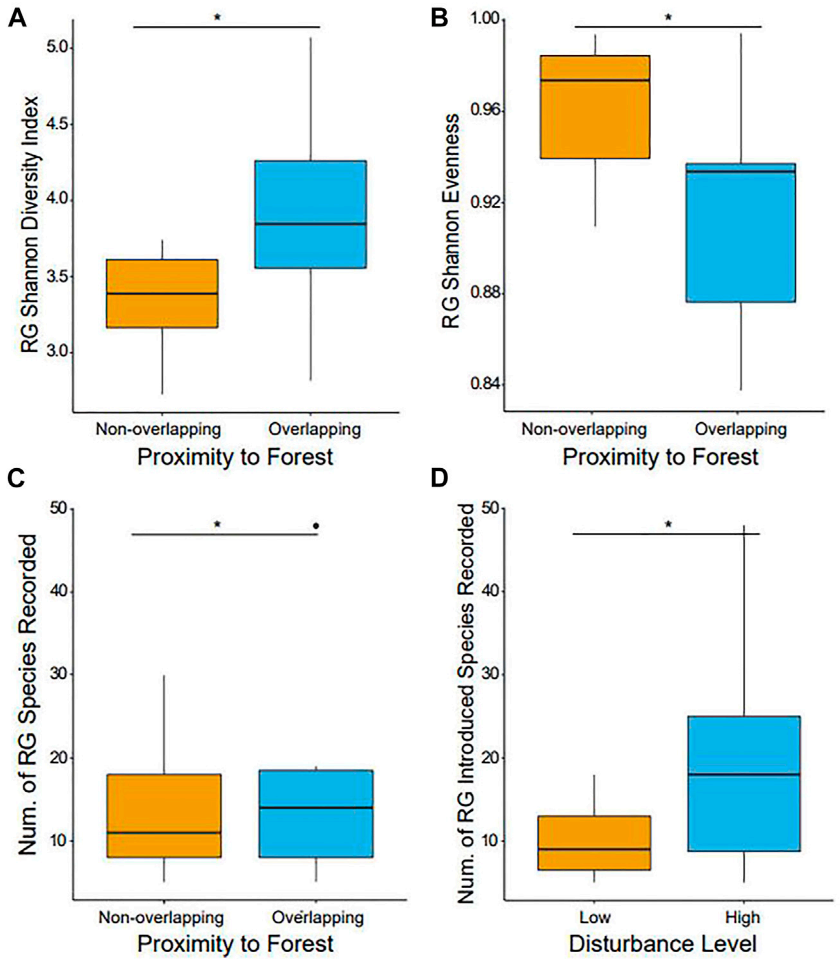

FIGURE 3 | Comparison of diversity measures for sites with different land use characteristics. **(A)** Shannon diversity index of research grade observations, **(B)** evenness of research graph observations, **(C)** number of research grade species, and **(D)** number of research grade introduced species are shown.

birds was only influenced by observer education level ($X^2 = 26.53$, $DF = 4$, $p < 0.0001$), with the number of bird observations significantly increasing with education level (**Figure 5C**). Finally, we found that the percentage of other taxa observations (not plants, insects, or birds) significantly increased with the number of observers ($X^2 = 21.17$, $DF = 1$, $p < 0.0001$; **Figure 5D**). The final model for other taxa also included the factor of educational level but this was not significant ($X^2 = 6.29$, $DF = 4$, $p = 0.18$).

A BioBlitz was performed at 55% of the sites. After removing outlier sites that had unusually high numbers of observations (one that did and one that did not perform a BioBlitz), we found that sites that performed a BioBlitz collected on average 285.8 ± 62.95 (mean ± st. error) total observations and 122.1 ± 23.25 research grade observations compared to an average of 67 ± 13.3 total observations and 25.75 ± 5.02 research grade observations at non-BioBlitz sites. The performance of a BioBlitz significantly increased the number of total ($t = -3.40$, $DF = 9.76$, $p = 0.007$; **Figure 6A**) and RG ($t = -4.051$, $DF = 9.80$, $p = 0.0024$; **Figure 6B**) observations collected in iNaturalist, as well as the number of research grade species detected ($t = -3.24$, $DF = 10.95$, $p = 0.008$; **Figure 6C**). In addition, we also found a significant effect of holding a BioBlitz on the diversity of species observed at a site ($t = -2.977$, $DF = 7.63$, $p = 0.019$; **Figure 6D**), with sites that held a BioBlitz showing increased Shannon diversity indexes (mean ± st. error: BioBlitz= 3.64 ± 0.14; no BioBlitz= 3.01 ± 0.16). The increased number of observations detected in association with holding a BioBltiz was not simply the result of an increase in the number of observers participating; there were no significant differences in the number of observers between sites that did or did not have a BioBlitz ($t = -1.41$, $DF = 11.98$, $p = 0.18$).

Finally, our species accumulation curves suggest that the asymptote for the number of species detected was not reached in our study. When considering the continuous addition of more observers, sampling sites, or sampling months, the cumulative number of species detected continued to

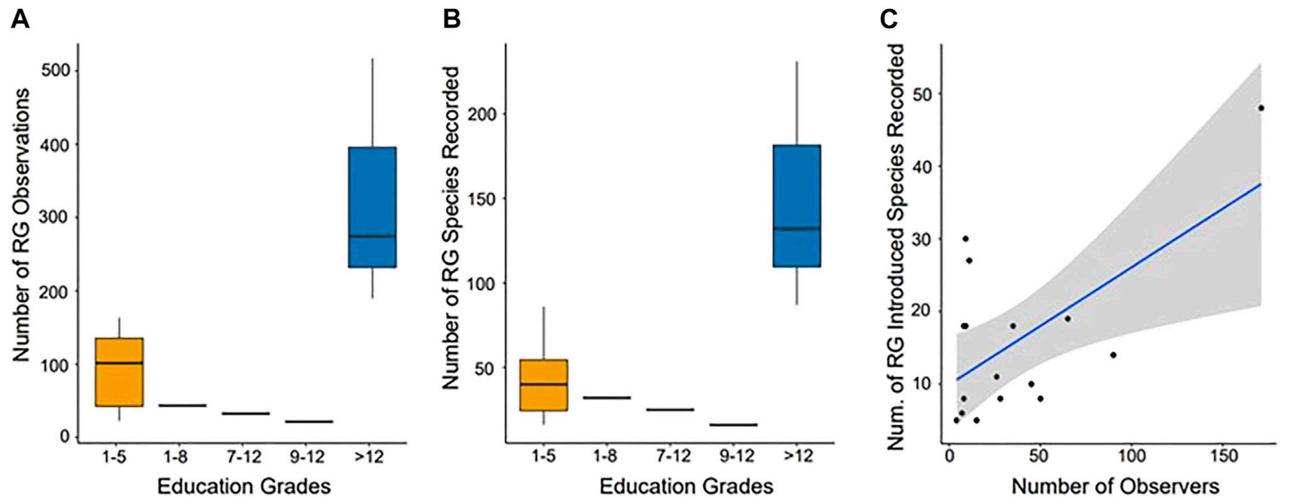

FIGURE 4 | Observer characteristics influencing the amount of research grade data collected. The number of **(A)** observations and **(B)** species recorded as research grade were influenced by education level. The large contributions of college-level students (>12 education grades) were the primary driver of this relationship. **(C)** The number of introduced species recorded as research grade increased with the number of observers.

increase without clear signs of leveling off (**Figure 7**). Our data do not seem to indicate a duplication of effort among our sites and observers, and suggest additional observers, sites, and time are needed to identify all species present in Humboldt County.

DISCUSSION

The field of Translational Science Education (TSE) was recently proposed (Sutherland et al., 2019) to formalize the need for a legitimate experiential learning (in accordance with Next Generation Science Standards) that simultaneously benefits students and the scientific knowledge base by building on iterative, trusted two-way relationships between researchers and educators and thus "enhance scientific literacy and discovery alike". Here we provide the first formal example of conducting TSE, focused on biodiversity surveys recorded in iNaturalist by students and teachers. Below we describe how this work applies to the six elements of TSE: decision-framing, collaboration, engagement, commitment, process, and communication.

Decision-Framing

Across the globe, environmental shifts are happening faster than they can be tracked by researchers, especially given limited science funding. This means that citizen science efforts are increasingly important for monitoring strategies. One of the primary goals of this TSE effort on the side of the researchers was to understand the effects of urbanization on species diversity in the coastal redwoods system. Specifically, the Tiny North Coast Places project tested predictions related to the coast redwood study design while also suggesting areas for future research. Our project generated more than enough high-quality information to reach this goal and test the predictions. As expected, student observations showed higher native species diversity at sites near large forests and fewer introduced species in less disturbed areas (**Figure 3**). However, they also indicated more introduced species and lower evenness near large forests (**Figure 3**), suggesting future citizen science efforts could be conducted to investigate the complicated relationships between land use and species diversity in Humboldt County.

We also were able to reach our goal of understanding how the structure of our project would affect the amount and type of data generated. We found that the education level of the participants had a significant effect on the amount of data they collected (**Figure 4**), as well as the taxa they tended to photo-observe (**Figure 5**). In addition, sites which performed BioBlitzes collected significantly more data (**Figure 6**), suggesting that gamifying photo collection can lead to larger amounts of data. As the number of participants did not significantly differ between sites that did and did not hold a BioBlitz, these results suggest that BioBlitzes can generate a larger number of observations per participant. While we can only speculate, it is possible that this increase might be due to increased excitement or competition among participants, or because students had more time to take photo-observations than during a typical day. Regardless of whether a BioBlitz was performed, it is clear that species continued to accrue throughout 2018 for each location (**Figure 7**). Modeled estimates of how many more observations would be required to record all species in a year could help motivate participants to want to do more. Finally, some diligent observers in the community even expanded the iNaturalist range map for a few species when they collected "first" photo-observations for Humboldt County, before, during, and after 2018 (e.g.,Common Shiny Woodlouse (*Oniscus asellus*; RG), Granulated Ground Beetle (*Carabus granulatus*; RG), Collared False Darkling Beetle (*Phryganophilus collaris;* RG)). While it is too early to know whether these previously unknown range occurrences are a result of climate change or something else, it is certainly true that they would not have been formally

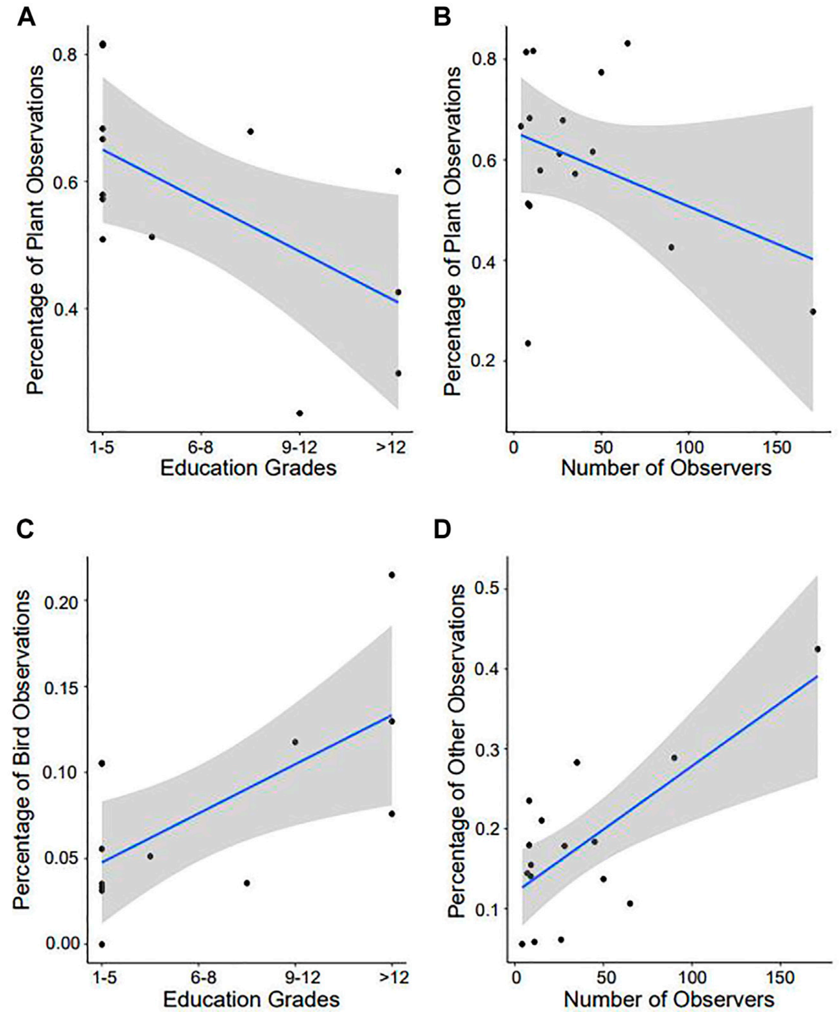

FIGURE 5 | Observer characteristics shaping type of taxa data collected. Figures representing observer characteristics that significantly influenced the percentage of plants, birds, or other taxa are shown. The percentage of plant observations was significantly influenced by **(A)** increasing education level and **(B)** increasing numbers of observers. **(C)** Percentage of bird observations increased with education level, and **(D)** percentage of other observations increased with increasing numbers of observers. Regression lines show linear regressions with 95% confidence intervals.

documented without the participation of our newly established TSE naturalists.

In terms of project impact on learning, we did not collect quantitative information on how well educator goals were met. While educators were active participants in this project, no quantitative metrics by which they could measure student engagement or learning throughout the project were collaboratively established. Qualitatively, educators at the Sequoia Park Zoo reported observing enthusiasm in student participants during organized BioBlitzes, as well as increased practices of environmental stewardship over the course of the day for students visiting on field trips (e.g. returning animals to where they were found after photo-observing them, keeping flowers attached to the living plant to minimize impact while taking photo-observations).

Collaboration

Starting with one small group in 2017 (Kindergarten through 5th grade students ranging in age from 4 to 11 years old) at Arcata Elementary School, this project quickly developed into a large collaboration of over 700 observers and 438 identifiers in 3 years among 19 different North Coast locations (**Table 1**). By coordinating directly with teachers and staff to create gamified BioBlitzes within this large community, this project was able to generate even more valuable data on species diversity than if the BioBlitzes were never implemented (**Figure 6**). In addition, all educators had access to the community-wide umbrella project on iNaturalist, allowing them to show students the results of their classes' contributions in the context of the entire project. Throughout the project, we observed that the relationships between the researchers, the educators, and the parent

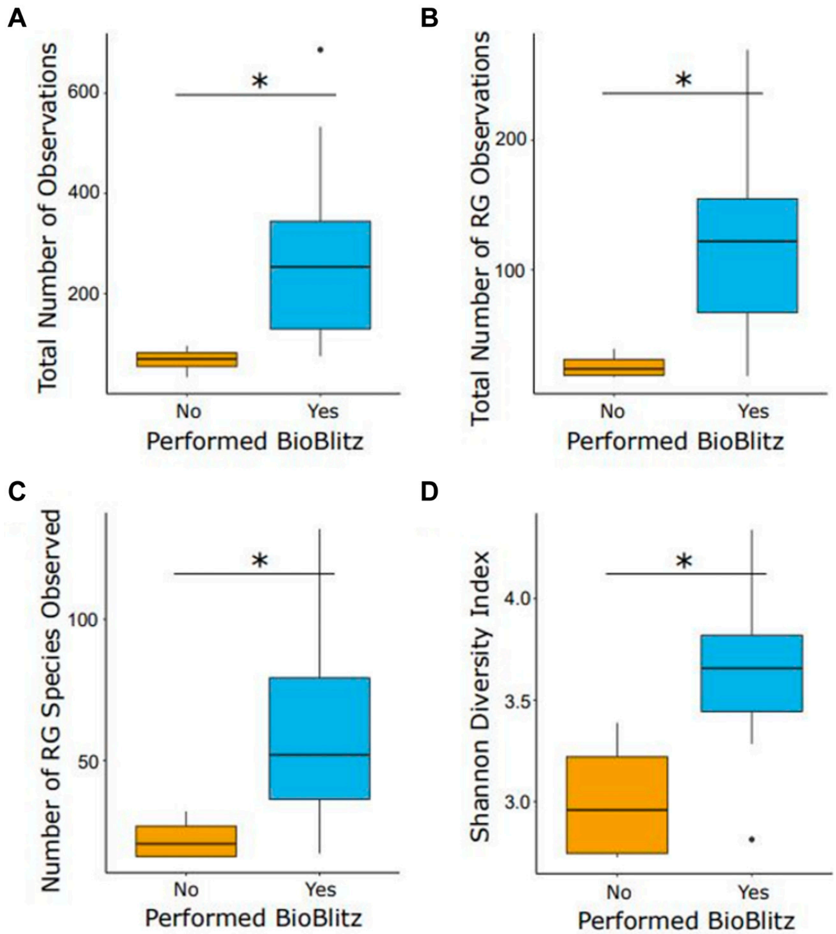

FIGURE 6 | Effect of BioBlitz on amount of data and diversity recorded. Boxplots showing the **(A)** total number of observations, **(B)** number of Research Grade (RG) observations, **(C)** number of RG species detected, and **(D)** Shannon diversity index for sites that did or did not perform a BioBlitz are shown. Performing a BioBlitz increased the Shannon diversity recorded at sites. Significant differences are shown with an * representing $p < 0.05$.

volunteers were key to sparking enthusiasm and reinforcing participation, especially when the observations were identified quickly and the students were allowed to review their observations online. We anticipate that this interactive TSE effort will continue to reinforce itself and grow as the word spreads that citizen science is an effective way to monitor, and therefore conserve, our coastal redwood ecosystem species.

Engagement

This project engaged TSE participants by trying to show them the fun in finding and photo-observing the living creatures in their own environments, gamifying biodiversity surveying much like a Pokemon Go game but with real conservation implications (Dorward et al., 2016). Armed with smartphone technology, these citizen scientists practiced connecting with, learning about, and sharing the nature around them, which seemed to make them feel included in the scientific process. As anyone with access to a smartphone can take photo-observations while out in nature, TSE presents opportunities to engage communities and students that are historically disengaged from nature as well as opportunities to connect with nature regardless of where one lives. The result was the enthusiastic collection of 5,306 research grade observations representing over 529 species, monitoring roughly 21% of the known (and some unknown) species ever observed in Humboldt County (**Figure 7**). Students were shown the results of their engagement throughout the project, with teachers sharing which teams had found the most species and which species were observed the most throughout the project. On days when a BioBlitz was conducted, students got to see the results of their friendly competition on the same day.

Commitment

Finding the champions from each school and non-profit location to commit to the project was one of the great successes of the Tiny North Coast Places project (see acknowledgements). Now, because of this work, there is a small, activated, Humboldt County TSE effort

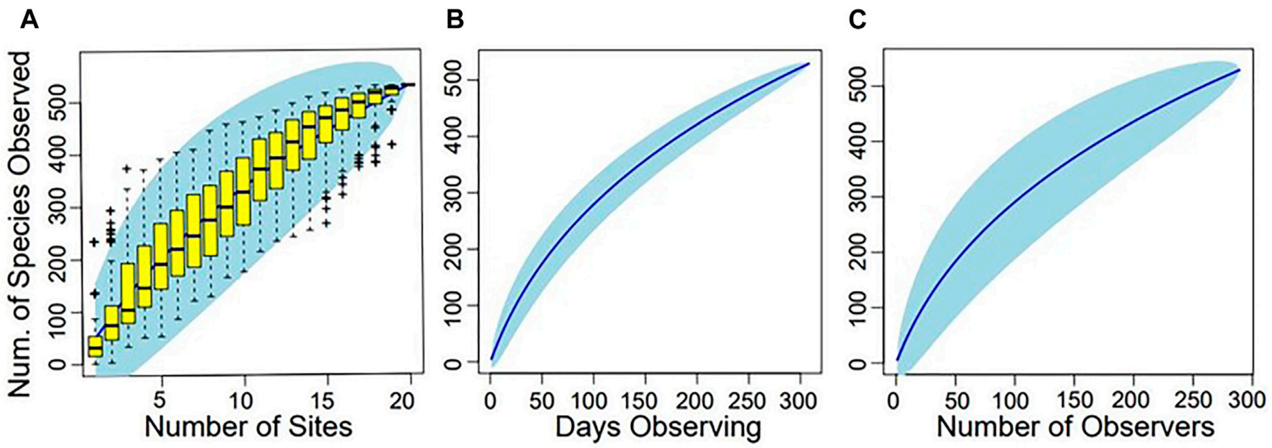

FIGURE 7 | Species accumulation curves over increasing numbers of **(A)** sites, **(B)** observation days, and **(C)** observers. None of the curves appear to have reached an asymptote, indicating sampling efforts were not duplications and further effort is needed to capture the full number of species present in the Humboldt County area.

that is available to help plan, coordinate, and curate future iNaturalist based BioBlitz and Collection Projects. There are already signs of further community commitment to the project, including requests by schools for more iNaturalist adventures (e.g., Jacoby Creek School, Fuente Nueva School, Humboldt State University) and well-attended presentations that took place in the summer and fall of 2019 (SHIFT teachers' workshop July 2019, zoo conservation lecture November 2019).

Process

Starting this TSE effort took time and dedication as the participants slowly became aware of the potential of the iNaturalist platform. Over time, they gradually realized how effective a tool it could be for linking education, science, and community. Teachers were initially introduced to iNaturalist during a January 2018 STEAM conference presentation. By showing them how using the platform was essentially an enjoyable shortcut toward fulfilling grade level appropriate NGSS/STEAM and physical fitness standards, that presentation generated the interest and participation of teachers and students from over 16 schools across Humboldt and Siskiyou Counties. The successful evolution of this process meant that, in the end, there was more buy-in from participants and with enough data to show scientific results, we now have a small TSE effort that could potentially lead to a tipping-point toward a truly integrated culture of conservation-oriented citizen scientists in Humboldt County.

Communication

Communication was a challenge but also a strength of the Tiny North Coast Places project. The use of a well-established, 10-year-old citizen science platform to share data and ask questions of each other greatly supported outcomes. Within the iNaturalist platform, not only do the observers contribute to science and inform the community of what would otherwise be unknown to science, but there is also a social media element allowing educators and supervised students to question scientists, naturalists, and other collaborators about the species and data that they are photo-collecting.

One of the challenges was in successfully communicating the strength and value of this particular platform to new users who were unfamiliar with both natural history and citizen science, especially in a technology-saturated learning environment. Further, it will be both interesting and challenging to assess whether the 700+ newly recruited iNaturalist participants have enjoyed this particular citizen science process enough to remain engaged for the future. With this in mind and for broader outreach in Humboldt County, the results of this project were presented to 10 educators at a local Humboldt County educational conference in 2019 to further communicate the scientific and educational potential of networking through the iNaturalist platform.

Another challenge on the part of the researchers was communicating the goals of the project to students in an age-appropriate manner, and helping students draw connections between their photo-observations and the curriculum they were meant to learn. However, teachers involved in the Tiny North Coast Places project framed the data collection and analysis within the NGSS standards according to students' grade levels. They were able to use crosscutting concepts to illustrate core ideas in the life sciences, linking the scientific practice of data collection to educational outcomes (e.g. NGSS standard 2-LS4-1: Make observations of plants and animals to compare the diversity of life in different habitats). They were also able to share the project results with their students in real time while the project was conducted as well as after the project finished, as all participating teachers have continued access to the entire Tiny North Coast Places umbrella project and its associated data on iNaturalist. The results shared here will also be provided to all of the participating educators, allowing them to show their students the scientific outcomes of their data collection efforts. The data and findings generated in this project could also

BOX 1 | Translational Science Education Tips.

- Engage early and often—From the beginning, it is vital to provide training to teachers who will be the primary people responsible for ensuring student engagement and success. Taking the time at the initiation of the project to explain how citizen science effort can fulfill NGSS science standards and how to collect high-quality data, as well as regular check-ins about the project, will ensure teacher buy-in and set up successful collaborations that can be maintained long-term.
- Make it fun—Utilizing gamified BioBlitz surveys can ensure student participation and highlight the fun that can be had with observing nature. Keeping the focus on the organisms, with technology only a useful tool, can ensure citizen science efforts are educational as well as fun.
- Have a goal—Setting individual goals for the project for all participants can ensure continued participation. Student-centric goals could be centered around identifying and learning about the life history of commonly photographed organisms, while researcher-centric goals could focus on collecting enough data to approach the asymptote in species accumulation curves such that almost all species in an area have been recorded.
- Use flexible and functional social media—Engaging with social media opportunities on iNaturalist and similar platforms provides another way for students and scientists to engage and share knowledge.
- Find a champion(s)—Finding an interested contact person at each location is vital to ensure citizen science efforts are sustainable and long-lasting. While this is made challenging due to staff and student turnover, finding even one champion can ensure projects continue multiple years.
- Target the data collection to the participants—Students of all ages were capable of photo-collecting research grade observations of a diverse range of species (**Figure 5**), but the age of the participants can determine the type of organisms that are photo-collected. In particular, younger students readily collected photos of plants and insects, but older students (high school and college-aged) were much more likely to record birds and other observations (**Figure 6**). Strategically choosing research questions and learning goals that take into account student age can ensure a successful collaboration.

be simplified and summarized into interactive lesson plans such as Data Nuggets, free classroom activities that give students practice using the scientific method with authentic datasets (Schultheis and Kjelvik 2015).

CONCLUSION AND NEXT STEPS

Throughout this 3-years TSE process, we gained some on-the-ground perspective on how to ensure success in future TSE citizen science efforts and on ways in which the structure of TSE efforts can shape the type of research data collected. We believe the general TSE building tips summarized in **Box 1** will help.

In this TSE project it was outside the scope of our study to quantify the effects of the TSE framework on student learning. However, we encourage future researchers using a TSE framework to work collaboratively with educators to develop metrics to measure student learning and educators' success from the beginning of the project. In addition, future studies could examine how relationships between scientists, educators, and students impact the participation and enthusiasm of those involved in TSE project. Another promising future direction resulting from this project is to investigate how gamifying citizen science, as we did here, shapes both long- and short-term appreciation of local biodiversity and conservation. Finally, we encourage future TSE efforts to put greater emphasis on studying not just the efficacy of TSE on student learning, but also how seeing the results of their efforts impacts student learning and interest in future citizen science efforts.

The Tiny North Coast Places project demonstrates one way to build on all the elements of TE (i.e., decision-framing, collaboration, engagement, commitment, process, and communication) to create a TSE effort with an extremely flexible, interactive and user-friendly, citizen science/crowdsourcing platform: iNaturalist. By creating gamified BioBlitz projects and one-year Collection Projects to generate baseline species lists for each Tiny North Coast Places polygon, this project shows that citizen scientists of all ages can have fun learning as they simultaneously generate scientifically sound phenological and range data for Coastal Redwood ecosystem species. Significantly, the data generated in the first 2 years showed some evidence of an urbanization gradient while also suggesting avenues of future research. Even more significantly, the citizen scientists who generated these data enjoyed being the experts in their own ecosystems, whether in a schoolyard or at the zoo. The Tiny North Coast Places project successfully encouraged budding naturalists to be the heroes in our ongoing, global conservation efforts by seeking those meaningful, one-on-one relationships with the *in-situ* organisms living around them. By continuing to optimize and broaden data collection by citizen scientists, the community can continue to generate observations valuable and informative to effective conservation actions.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: The data and code that support the findings of this study are openly available in Environmental Data Initiative at https://doi.org/10.6073/pasta/ead637f72df3efc6300d508840bdef7b. In addition, data deemed research-grade by iNaturalist that were used in this project can be found in GBIF form at https://doi.org/10.15468/ab3s5x.

AUTHOR CONTRIBUTIONS

EV developed the project and led the data collection. CN served as an organizer and champion of the project at the Sequoia Park Zoo. TM and AG retrieved data from iNaturalist, while AG and AY analyzed the data. All authors contributed to the writing of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.800433/full#supplementary-material

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