Received: 24 April 2025 | Accepted: 4 December 2025
DOI: 10.1002/2688-8319.70173

BRITISH ECOLOGICAL SOCIETY Ecological Solutions and Evidence

RESEARCH ARTICLE

Participatory citizen science data complements agency-collected data for species inventories

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Funding information
U.S. Department of Agriculture, Hatch, Grant/Award Number: FLA-FTL-006297; U.S. Department of Agriculture, McIntire-Stennis Program, Grant/Award Number: FLA-FTL-006659

Handling Editor: Rachel White

Abstract

1. Species inventories—comprehensive lists of all species in a given location—inform management decisions and conservation goals. In some instances, citizen science platforms may further contribute to species inventories, especially on public lands. Despite the growing availability of citizen science data, it is not known how these data compare to species inventories conducted by state agencies.
2. We investigated how species inventories—across many taxonomic groups—conducted by a government agency (the Florida Department of Environmental Protection) for 39 state parks in Florida can be complemented by citizen science data generated from iNaturalist and eBird. We also investigated what, if any, characteristics of species and parks contribute to the difference in contributions made by citizen science.
3. Across all parks, citizen science data recorded novel species in multiple taxonomic groups, with the largest contributions being insects and birds. However, the proportional contribution of citizen science data varied greatly by park, with a minimum of 2.9% and a maximum of 79.1% of species in each park detected only by citizen science.
4. Most species in the examined state parks that had a designated conservation status from NatureServe were documented by agency data. However, citizen science sources did provide the only presence data of a small number of species of conservation concern (species with 'Vulnerable', 'Imperiled' and 'Critically Imperiled' statuses). Park characteristics, such as number of unique citizen science observers and observations, park acreage, population of the city in which the park is located and annual visitation, did not explain the over or under proportional sampling by citizen science data.
5. *Practical implication*. Citizen science data can improve the completeness of taxonomically diverse species inventories by complementing data collected by government agencies. These data should be increasingly recognized for their value and curated in ongoing species inventory monitoring approaches.

KEYWORDS
citizen science, complementarity, eBird, Florida, iNaturalist, species inventories

1 | INTRODUCTION

Species monitoring is an important part of biodiversity research and conservation amid ongoing global biodiversity loss (Chandler et al., 2017; Díaz-Calafat et al., 2024; Paterson et al., 2008). Species occurrence data are key information for biodiversity monitoring and conservation because they link taxa within a spatial and temporal context (Chandler et al., 2017; Petersen et al., 2021; Rondinini et al., 2006). In addition to general documentation of biodiversity, species monitoring can also provide valuable insights into ecosystem-level threats and inform conservation actions. For example, monitoring of species occurrences is used to track the biological statuses of species of conservation interest as designated by the Endangered Species Act (Evansen et al., 2021). Adequate data are important for policy and decision-making, yet professional and government agency data collection do not always yield enough data to understand the function and structures of ecosystems (Conrad & Hilchey, 2011).

Species inventories, defined here as the cumulative list of species seen within a specific boundary (see Methods), are critical components of monitoring at global (e.g. COP and IUCN; Dalton et al., 2024; International Union for the Conservation of Nature [IUCN], 2024), national (Species Protection Indices; E.O. Wilson Biodiversity Foundation, 2024) and state levels (Association of Fish and Wildlife Agencies [AFWA], 2022). Acquiring biodiversity data is complex in that there are many different techniques for monitoring different species, with as many as 15,000 monitoring schemes globally (Moussy et al., 2022). For management agencies, species inventories directly inform conservation priorities, habitat restoration decisions and the allocation of limited monitoring resources (Katzer et al., 2025). For example, agencies use these lists to decide where to focus restoration efforts, identify habitats that require additional protection, and track progress towards state and national biodiversity targets.

Comprehensive data collection is time-consuming, expensive and requires expertise, potentially limiting the geographic scale of monitoring efforts (Callaghan et al., 2025; Dimson et al., 2023; Roberts et al., 2022). This is especially true, given that biodiversity is always changing, species are shifting ranges, and local extinction and colonization are taking place (Weiskopf et al., 2020). Such constraints lead to data collection that tends to be biased towards charismatic species (Díaz-Calafat et al., 2024; Moussy et al., 2022), threatened and endangered species (Boakes et al., 2010) and large-bodied species (Callaghan et al., 2021; Turley et al., 2024). To address constraints and their resulting biases, crowdsourcing biodiversity data collection through citizen science projects can be valuable (Chandler et al., 2017; Conrad & Hilchey, 2011; Díaz-Calafat et al., 2024; Dimson et al., 2023; Guerrini et al., 2018; McKinley et al., 2017). There is support, including US government legislation, for the use of citizen science or crowdsourced data (e.g. Guerrini et al., 2018). For management agencies, the utility of additional data to species inventories by citizen science lies in the potential to fill taxonomic and spatial gaps in existing inventories (e.g. Katzer et al., 2025), providing early warnings of changes in species composition and reducing the time between required updates. In this way, there is potential for citizen science data to make inventories more actionable for short-term management decisions.

Despite the potential of citizen science data, there is a lack of 'guidelines' on how and when government agencies and policymakers should use citizen science data (Moussy et al., 2022). Part of this lack of guidelines is because of persistent concerns about data quality and reliability (Conrad & Hilchey, 2011; Mason, Bratton, et al., 2025b). Such concerns have led to scientists sometimes declining to use or publish analyses based on citizen science data due to perceived insufficient quality assurance or control (Burgess et al., 2017). On the policy side of land management, citizen science data are used in environmental reviews (Callaghan et al., 2025), but are not typically explored as reliable data sources (Conrad & Hilchey, 2011). Policy guidance for integrating citizen science into biodiversity monitoring varies considerably across different parts of the world, being relatively well developed in many European countries (e.g. Haklay, 2015; Schade et al., 2021). Yet, the formal development of policy related to citizen science remains more limited in the United States, particularly at the state level. Within the United States, approaches to the use of citizen science can differ between federal and state agencies; and even within a state, different agencies can have different viewpoints about the potential of citizen science data in biodiversity research and monitoring (Mason, Bratton, et al., 2025b). Despite the lack of general guidance, there is an increasing use of citizen science data by government agencies in a policy context (Callaghan et al., 2025), making it important to evaluate the extent to which citizen science complements or enhances other species inventory approaches.

Evaluations of the quality of citizen science data have found that in some instances data generated from citizen science are comparable in quality to professional data (Callaghan et al., 2020; Guerrini et al., 2018; Herrera et al., 2025; Roberts et al., 2022; Wittmann et al., 2019), while in other instances quality is lacking (Aceves-Bueno et al., 2017; Díaz-Calafat et al., 2024). By increasing the number of observers, large-scale, unstructured citizen science projects can collect more data temporally and spatially (Dickinson et al., 2010). Because participants are often afforded freedoms in the frequency with which they collect data by large, unstructured projects (e.g. iNaturalist, eBird) there are biases that are structured temporally, spatially, and taxonomically in the data collected

(Backstrom et al., 2025). Among iNaturalist users, for example, more data are collected during the summer than the winter, on weekends compared to weekdays, in developed areas compared to rural areas, and with preference for insects and plants over other species (Di Cecco et al., 2021). In spite of these biases, with increases in data collection, previous work has shown that these projects can complement professionally collected data for frogs (Callaghan et al., 2020), invasive plant distribution (Dimson et al., 2023), reef fishes (Roberts et al., 2022), bird species richness (Callaghan et al., 2018), invasive mosquito monitoring (Pernat et al., 2021) and water quality assessments (Hadj-Hammou et al., 2017).

Despite the potential utility of large-scale projects like eBird and iNaturalist that together host millions of users and billions of observations, comparisons of professional/academic data and citizen science data are still relatively uncommon in the literature (Díaz-Calafat et al., 2024; Turley et al., 2024). Most case studies tend to be focused on data quality only (Pernat et al., 2021) and are narrowly focused on specific taxa (e.g. frogs or fish) with few focusing on multi-taxa comparisons of biodiversity. Moreover, the completeness and utility of a given inventory can vary among locations depending on factors such as size, accessibility and levels of public visitation (Boakes et al., 2010). Citizen science and agency data are likely to differ in the species they capture because they are generated under different motivations. Agencies often conduct targeted surveys for particular taxa or species of concern (i.e. higher conservation status) and have more structured sampling in some instances. But in contrast, citizen science participants tend to sample detectable or charismatic taxa (Callaghan et al., 2021). Additionally, there are many specialists among citizen science participants focusing on different taxa (Di Cecco et al., 2021). As a result, citizen science may complement agency data by filling gaps in certain taxa (e.g. insects and birds) or by capturing species that are overlooked during agency monitoring. But the ability of citizen science to complement agency data is likely to vary based on the conservation status of a species, or location-based variables like public accessibility, human population density of the area and miles of accessible trails (Mandeville et al., 2022). Therefore, in addition to evaluating the quality of data generated by citizen science (i.e. the comprehensiveness of citizen science compared to professionally collected data), examining how these comparisons vary based on different factors (e.g. data collection effort, geographic coverage or accessibility of surveyed locations) can highlight the circumstances in which citizen science data can provide the greatest added value to agency monitoring programmes.

Our overall objective was to investigate how citizen science data from broad-scale participatory citizen science platforms—iNaturalist and eBird—compare with government agency data (hereafter referred to as 'agency data') used to inventory and monitor species in Florida state parks. To do this, we (1) quantified the contributions of citizen science data compared to those of agency data in each park, (2) assessed differences in the taxonomic coverage of government data and citizen science data, (3) identified differences in species documented by the agency and citizen science data according to conservation status and (4) determined if any qualities of parks and their associated recreation opportunities were correlated to greater utility of citizen science data.

2 | MATERIALS AND METHODS

2.1 | Study area

We collected species inventories (i.e. lists of all known species existing in an area) generated for state parks in Florida, United States of America, to assess the utility of citizen science data. The state of Florida mandates under Florida Statute 253.034 that all government-owned lands, including the state park system, be monitored and managed by government agencies (Florida State-Owned Lands Law, 2022). Mandated monitoring therefore requires a distinct species list generated by professionals at state agencies. At the same time, state parks in general receive high annual visitation—over 28 million visitors in fiscal year 2022–2023 (Florida Department of Environmental Protection [FDEP], 2023), and these visitors sometimes cumulatively generate a species list via citizen science platforms. These different approaches allow for an extensive dataset for analysis and comparison. Within the Florida state park system, we chose to focus on parks with the most up-to-date state-led species inventories. This focus led us to select 39 state parks in northeast Florida with species inventories conducted by the Florida Department of Environmental Protection (FDEP) in their Administrative District 2 (Figure 1).

2.2 | Species inventories

We derived a species inventory—defined here as the cumulative list of documented presences of species within a defined boundary (Cutko, 2009; Ministry of Environment, Lands and Parks, Resources Inventory Branch, Terrestrial Ecosystems Task Force, Resources Inventory Committee [RIC], 1998; National Park Service [NPS], 2025)—for two different datasets: (1) agency data from FDEP and (2) citizen science data from eBird combined with iNaturalist. This usage follows standard practice in biodiversity monitoring, where inventories may be compiled at different 'intensity levels' ranging from simple presence/not-detected lists to estimates of relative or absolute abundance (Ministry of Environment, Lands and Parks, Resources Inventory Branch, Terrestrial Ecosystems Task Force, Resources Inventory Committee [RIC], 1998). National and international guidelines recognize that inventories typically begin with confirmed records of presence, while further vetting into Element Occurrences (EOs) or model-based occupancy estimates represent separate, more stringent approaches used for conservation assessments and management decisions (Cutko, 2009; MacKenzie et al., 2006). Accordingly, in this study, occurrence is used in the inventory sense: a documented presence of a species within the park boundary (confirmed record in space and time). This differs from model-based occupancy, which estimates the

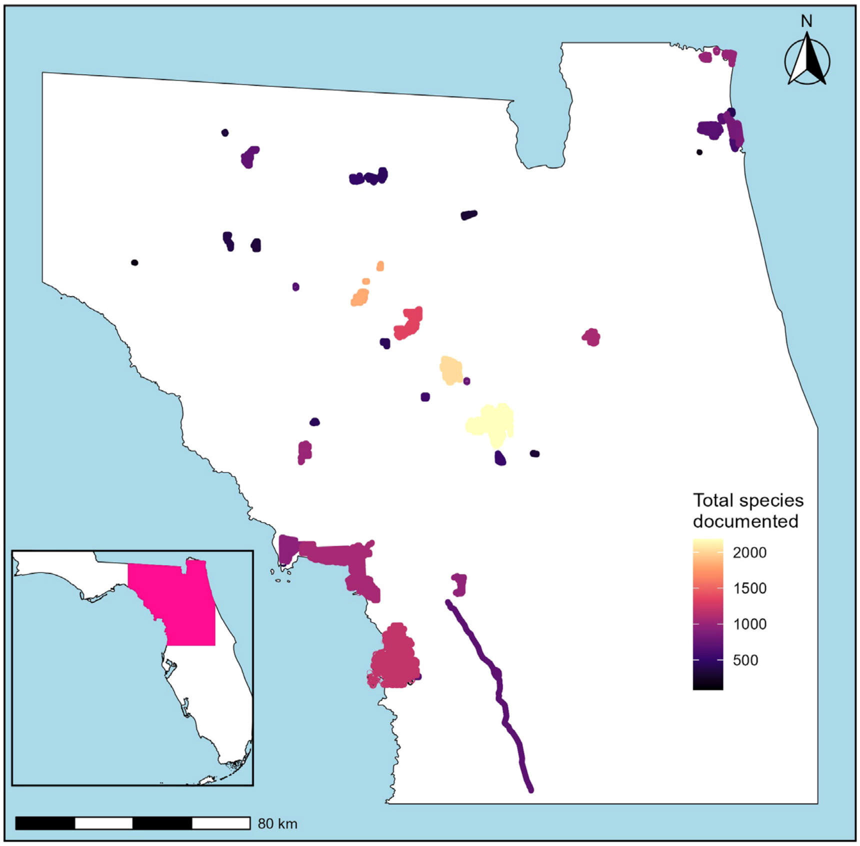

FIGURE 1 Map of 39 state parks in Florida in FDEP District 2 that have species inventories conducted by FDEP. Parks are coloured according to the total number of unique species documented by citizen science and FDEP combined. For visualization purposes, park boundaries are outlined with exaggerated thickness, making parks appear larger than their actual size.

probability of site use after accounting for imperfect detection (MacKenzie et al., 2006). We recognize the complexity of defining a species inventory (Guralnick et al., 2018) and acknowledge that our goal here was to provide a starting point to assess how citizen science data compares with the agency inventories currently used for management planning in the state of Florida in order to evaluate their potential complementarity. To ensure that our methodology is not inflating rare species observations from the citizen science dataset, we conducted an exploratory analysis and found that both FDEP and citizen science data documented rare species in parks (see full details in Figure S1).

2.3 | Agency data

To update management plans for parks every decade, FDEP maintains presence-only species lists for each park they manage. Lists are made cumulatively, originating from the time the park was acquired and are revised every decade. Species are added or removed during times of revision if there is consensus among district and park biological staff to do so. As with many professional biodiversity inventories, survey effort and methodologies vary among parks depending on local capacity and priorities, which can introduce inconsistencies across inventories (Stohlgren et al., 1995). The Florida Natural Areas Inventory (FNAI) and academic partnerships are used for initial surveys and then data is mostly collected by Division of Recreation and Parks biologists. Other survey efforts happen incidentally during routine field work and resource management and through targeted monitoring efforts for specific, imperilled species (e.g. gopher tortoise [*Gopherus polyphemus*] burrow surveys or sea turtle [Family Cheloniidae] nest monitoring). During our data collection process, we discussed data availability with FDEP and learned that the most recently updated (in 2024) and therefore most up-to-date data were for 39 parks in their administrative District 2 (Figure 1). FDEP provided us with the species lists for these parks creating our FDEP-sourced dataset.

2.4 | Citizen science data

In addition to species lists based on government-led species inventories, we generated a citizen-science-sourced species list for each park by combining all eBird checklist observations and 'Research Grade' iNaturalist observations for each park. To generate a species list, we compiled eBird and iNaturalist data and summarized the list of unique species (i.e. if the same species was documented by both iNaturalist and eBird data, it was only recorded once per park). To match the scope of data from FDEP agency data, we included all eBird and iNaturalist data up to when we aggregated the data (see below).

eBird is a citizen science platform where users fill out electronic checklists to document their location, the date and time of observation, and the species and abundances of birds they see or hear. From checklist submissions, over 1.6 billion observations of birds have been contributed to the platform from over 930,000 users globally (Team eBird, 2024). eBird users record collection protocols followed for each checklist that is submitted to provide more information about data collection methods used. These include marking if a checklist contains all birds seen during the duration of birding (yes— complete or no— incomplete checklist) and whether the user was travelling, stationary, or is making an incidental observation (Cornell University, 2025). Data quality is controlled through a semi-automated process with pre-defined filters of expected birds and bird species counts based on the location and time of year. If a species or count exceeds these filters, it is checked by regional expert volunteers before being integrated in the dataset (Cornell University, 2023; Gilfedder et al., 2019). We obtained eBird data through a data request, which included all bird species observations recorded in the state of Florida up to June 2024 (eBird, 2024). These data were filtered to only include observations made in District 2 parks, which contained 1,861,625 eBird observations for use in this study. Most of the observations we used came from complete checklists (95.4%) made while following a travelling protocol (91.7%).

iNaturalist is another citizen science platform where users upload photographic or audio observations of any living thing, or evidence thereof, they encounter. When submitting an observation, users are offered suggested identifications based on a computer vision model trained with artificial intelligence influenced by species known to be present in the observation's location at the time the observation was made. Once submitted, other users confirm or provide alternate identifications on the observation. Observations of wild organisms that have more than 2/3rds consensus on species-level identifications and that pass the iNaturalist data quality assessment are considered 'Research Grade' (iNatHelp, 2024). Like eBird, iNaturalist has a large, global user base of over 3.5 million people that have collectively made over 232 million observations (iNaturalist, 2025). For our study, we gathered 'Research Grade' iNaturalist data through the Global Biodiversity Information Facility (GBIF) up to 25 June 2024 with a custom boundary that surrounded administrative District 2 (GBIF.org, 2024). Afterwards, the data were filtered to the parks within this district, resulting in 51,395 Research Grade iNaturalist observations for use in this study.

2.5 | Data integration

To analyse and compare the two species lists (FDEP and citizen science), we cleaned the data and performed taxonomic harmonization. In the FDEP dataset, O'Leno State Park and River Rise Preserve State Park, two parks that are close in geographic proximity, are combined. For consistency, and to match the methods of how FDEP aggregates their inventories, these two parks were treated as one throughout analysis for both the FDEP dataset and the citizen science dataset. To prepare for taxonomic harmonization, we cleaned the FDEP data to get rid of species that were not at the genus-species level (i.e. had extra characters indicating species notation other than genus-species ['sp.', 'ssp.', 'X' used for hybrids, etc.], only included a genus, or needed to be reduced to no longer include subspecies). After this cleaning, we investigated which FDEP data matched the iNaturalist Taxonomy. For all species that did not match iNaturalist after basic cleaning, we found synonyms using the taxize package in R (Chamberlain & Szocs, 2013) with the Integrated Taxonomic Information System as the database (db = 'itis'). Some synonyms still did not match iNaturalist, so we performed the same basic cleaning on the synonyms. After this step, any species names that had either no synonyms or no matches to the iNaturalist database ($n = 426$) were manually searched for on the iNaturalist website. iNaturalist recognizes old species names that underwent 'Taxon Changes' allowing us to update the species name when FDEP listed an out-of-date species name. This process also identified spelling inconsistencies that led to non-matches between the datasets. These species names were manually replaced with the name they are currently listed under in iNaturalist. When the FDEP name did not generate a match by searching the scientific name in iNaturalist, the common name listed in the FDEP dataset was referred to which could then be searched in iNaturalist to find a suitable scientific name. For the few species where no name could be found ($n = 52$, 1.2% of all FDEP-listed species), NA replaced the name given by FDEP and these species were filtered out and not included in the final FDEP dataset. Our final citizen science and FDEP datasets were then combined into one dataset.

2.6 | Statistical analysis

We summarized our dataset to obtain the number of species documented by FDEP and by citizen science platforms in each state park. Using a Shapiro–Wilk normality test from the stats package in R, we determined that the distributions of documented species were not normal for FDEP or citizen science across all parks. We then performed a non-parametric Wilcoxon signed rank test on the FDEP species counts and citizen science species counts using base functions in R. To comprehensively assess differences between the FDEP and citizen science datasets, we examined variation in species lists across taxonomic groups, conservation statuses and park-level characteristics. We summarized our combined dataset to organize species into taxonomic groups for comparison. A total of 96.33% of species in our dataset were in the kingdom Plantae or in one of seven classes in the kingdom Animalia. To ensure that our results were readable and representative of the data, we used these eight taxonomic groups (Plantae; Animalia: Mammalia, Aves, Reptilia, Amphibia, Insecta, Arachnida, Actinopterygii) in our analyses and presentation of results. For each taxon group, we obtained an FDEP species count and a citizen science species count in each park. The species included in these counts were those that were only documented by one source (either FDEP or citizen science). We performed Shapiro–Wilk normality tests for each taxon group and found that only Aves was normally distributed. For continuity across all eight groups, we chose to use a non-parametric test for all taxon groups and performed Wilcoxon signed rank tests (Taheri

& Hesamian, 2013). Given that we performed multiple statistical comparisons, we adjusted p-values using the Benjamini–Hochberg procedure to control for the false discovery rate (Benjamini & Hochberg, 1995). Next, to summarize the impact of conservation status on the number of species documented by citizen science, FDEP, or both, we obtained Global Conservation Status Ranks from NatureServe for all species in the United States (NatureServe, 2025) and assigned them to species in our combined (FDEP and citizen science) dataset by matching species names across our NatureServe and our combined datasets.

Lastly, we obtained variables for each park including the number of citizen science observers and observations from the iNaturalist and eBird dataset, the acreage of each park (Florida Department of Environmental Protection [FDEP], 2025), the populations of the cities (Carney, 2024) where each park is located, and the number of visitors in fiscal year 2022–2023 (FDEP, 2023). We made five univariate linear models with each of these variables as predictor variables with the response variable set as the relative difference of the number of species uniquely recorded by FDEP compared to the number uniquely recorded by citizen science expressed as a percentage: (number of FDEP species − number of citizen science species)/(number of FDEP species + number of citizen science species) × 100. We used the per cent difference because it provides a standardized metric for comparing the relative contribution of FDEP and citizen science species records across parks of varying sizes and differing levels of biodiversity. Raw species counts can be misleading as they are heavily influenced by park area, sampling effort or taxonomic focus, making direct comparisons potentially misleading. The use of per cent difference as the response variable allows us to directly assess the influence of each predictor variable on the park's skew towards more species reported by FDEP or citizen science data.

We chose to use linear models because we expected a linear relationship in each case, and the per cent difference response variable was normally distributed, as indicated by a Shapiro–Wilk test ($W = 0.961$, $p = 0.189$). For each linear model, we used the plot.lm function from base R to evaluate residual diagnostics, including residuals versus fitted values, Q–Q plots, standardized residuals versus fitted values, and standardized residuals versus leverage. Based on these diagnostics, we log-transformed four predictor variables—number of observations, number of observers, park acreage and population of the city the park is located in—to reduce the effect of large outliers on the model results. Afterwards, we found that all models satisfied the assumptions of the linear model. We note that exploratory analysis revealed that some of the predictor variables (e.g. park acreage, visitation, city population) are correlated. To avoid issues of collinearity and to isolate the independent effect of each hypothesized predictor on the response variable, we used univariate models rather than multivariate models. This approach allowed us to evaluate the relationship between each predictor and the response variable without confounding effects of correlated predictors. All statistical analysis and visualizations were made using the tidyverse collection of packages (Wickham et al., 2019) and base functions in R version 4.4.0 (R Core Team, 2024).

3 | RESULTS

Across all 39 parks (Figure 1), a total of 5220 different species were documented when FDEP and citizen science data were combined. Citizen science data documented 3326 different species and FDEP documented 3941 different species, with 1279 species unique to citizen science data and 1894 species unique to FDEP inventories. For 30 out of 39 parks, FDEP documented more species than citizen science data (Figure 2). FDEP consistently documented more species (median: 131 more; *p*-value <0.001), but for isolated taxon groups (insects, birds, mammals, arachnids and fish) there were instances where FDEP reported fewer species (Figures S2–S9). The three broad taxonomic groups with the most species documented in both datasets were plants, insects and birds (Figure 3a). In total, 79.5% of all species documented were in one of these three groups (38.3% plants, 33.6% insects and 7.6% birds). Across all parks, 1998 species of plants were documented: 854 listed only by FDEP (42.7%), 173 listed only by citizen science (8.7%) and 971 listed by both sources (48.6%). All species of plants documented by either source fell into one of 14 taxonomic classes, with the majority of plants (90.3%) being in Magnoliopsida or Liliopsida (Figures S10 and S11). For insects, 1747 species were documented across all parks: 582 listed only by FDEP (33.3%), 677 listed only by citizen science (38.8%) and 488 listed by both sources (27.9%). For birds, 397 species were documented across all parks: 21 listed only by FDEP (5.3%), 52 listed only by citizen science (13.1%) and 324 listed by both sources (81.6%). The contributions made by either data source varied among parks (Figure 3b–d). The proportional contribution of citizen science data varied greatly among parks, with a minimum of 2.9%, a maximum of 79.1% and an average of 28.5% of species in each park detected only by citizen science. All eight taxonomic groups had significant observed median differences between the number of species documented only by citizen science compared to those only documented by FDEP. Citizen science documented more species of arachnids (median: 4 more species than FDEP; adjusted *p*-value <0.001), birds (median: 45; adjusted *p*-value <0.001) and insects (median: 15; adjusted *p*-value = 0.0071). FDEP documented more species of plants (median: 144 more species than citizen science; adjusted *p*-value <0.001), reptiles (median: 18; adjusted *p*-value <0.001), mammals (median: 15; adjusted *p*-value <0.001), fish (median: 17; adjusted *p*-value <0.001) and amphibians (median: 7; adjusted *p*-value <0.001).

Out of all the species documented by either source, 4256 (81.53%) had a conservation status classified by NatureServe. Of these, most species were listed as 'Secure' (2324; 54.60%) or 'Unranked' (1104; 25.90%) with the remaining species listed as either 'Unrankable' (16; 0.38%), 'Not Applicable' (4; 0.09%), 'Apparently Secure' (587; 13.80%), 'Vulnerable' (158; 3.71%), 'Imperiled' (39; 0.92%), 'Critically Imperiled' (23; 0.54%) or 'Possibly Extinct' (1; 0.02%) (Figure 4). Citizen science made the largest total and percentage-wise contribution towards documenting species listed as 'Unranked', documenting 42.84% of species (473 out of 1104 species) that would be undocumented otherwise. In comparison,

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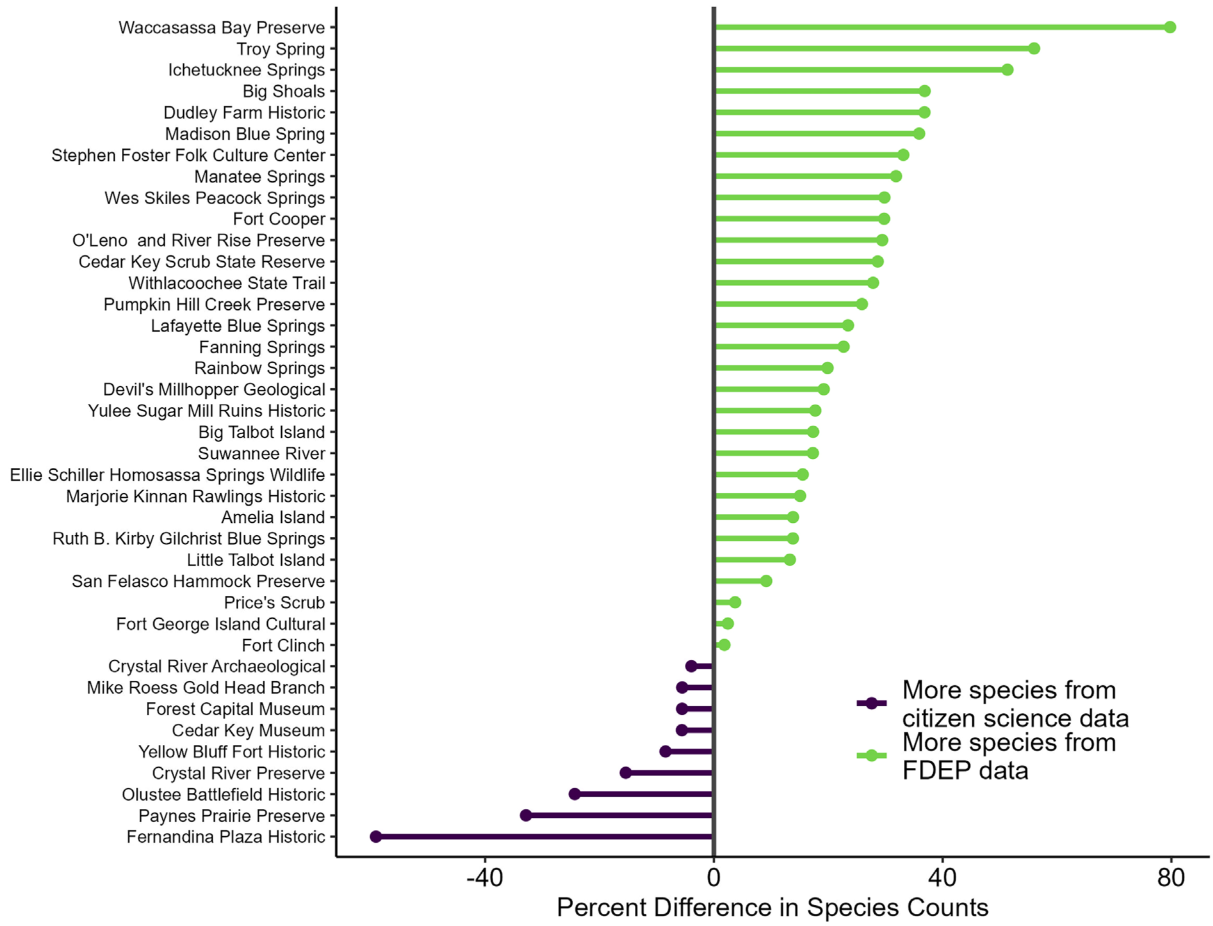

FIGURE 2 The per cent difference in FDEP and citizen science counts for each park. Per cent difference is calculated as (number of species documented by FDEP – number of species documented by citizen science)/(number of species documented by FDEP + number of species documented by citizen science) × 100.

FDEP uniquely documented 34.60% of 'Unranked' species (382 out of 1104 species) with the remaining 22.55% of species (249 species) documented by both citizen science and FDEP. Excluding species with 'Variant' Global Conservation Status Ranks ('Unrankable', 'Unranked' and 'Not Applicable' in this case), the proportion of species documented only by FDEP increases as the level of species imperilment increases. FDEP alone documented the only 'Possibly Extinct' species (*Crataegus flava*). Most 'Imperiled' and 'Critically Imperiled' species were also only documented by FDEP (71.79% [28 species] and 82.61% [19 species], respectively) (Figure 4).

When we compared the relative difference between the number of species uniquely documented by FDEP and citizen science, we found no significant relationship with unique citizen science observers (estimated effect = −2.273; p-value = 0.447; adjusted R^2 = −0.010; Figure 5) and the number of citizen science observations in each park (estimated effect = −2.321; p-value = 0.272; adjusted R^2 = 0.006). This result indicates that there is no relationship between parks with more observations and more observers and the number of species provided by citizen science. We found moderate evidence of a significant positive trend between park acreage and the per cent difference in species count by source (estimated effect = 3.283; p-value = 0.042; adjusted R^2 = 0.083). There was no significant relationship between per cent difference in species count by source and the population of the city the park is located in (estimated effect = −2.027; p-value = 0.241; adjusted R^2 = 0.011) or the number of park visitors (estimated effect = 0.00001; p-value = 0.699; adjusted R^2 = −0.026).

4 | DISCUSSION

Comprehensive species monitoring is a key component of land management that requires significant investments of time and labour-intensive techniques to execute. Across 39 Florida state parks, we found that agency data documented more species than citizen science sources. However, separating species according to broad taxonomic groups revealed that citizen science data filled in considerable gaps for certain groups of species. Citizen science sources documented many species of insects and birds that were otherwise undocumented across most parks. Citizen science data also made notable contributions for plant species. These taxonomic trends emerged even though there was high variability in the proportional

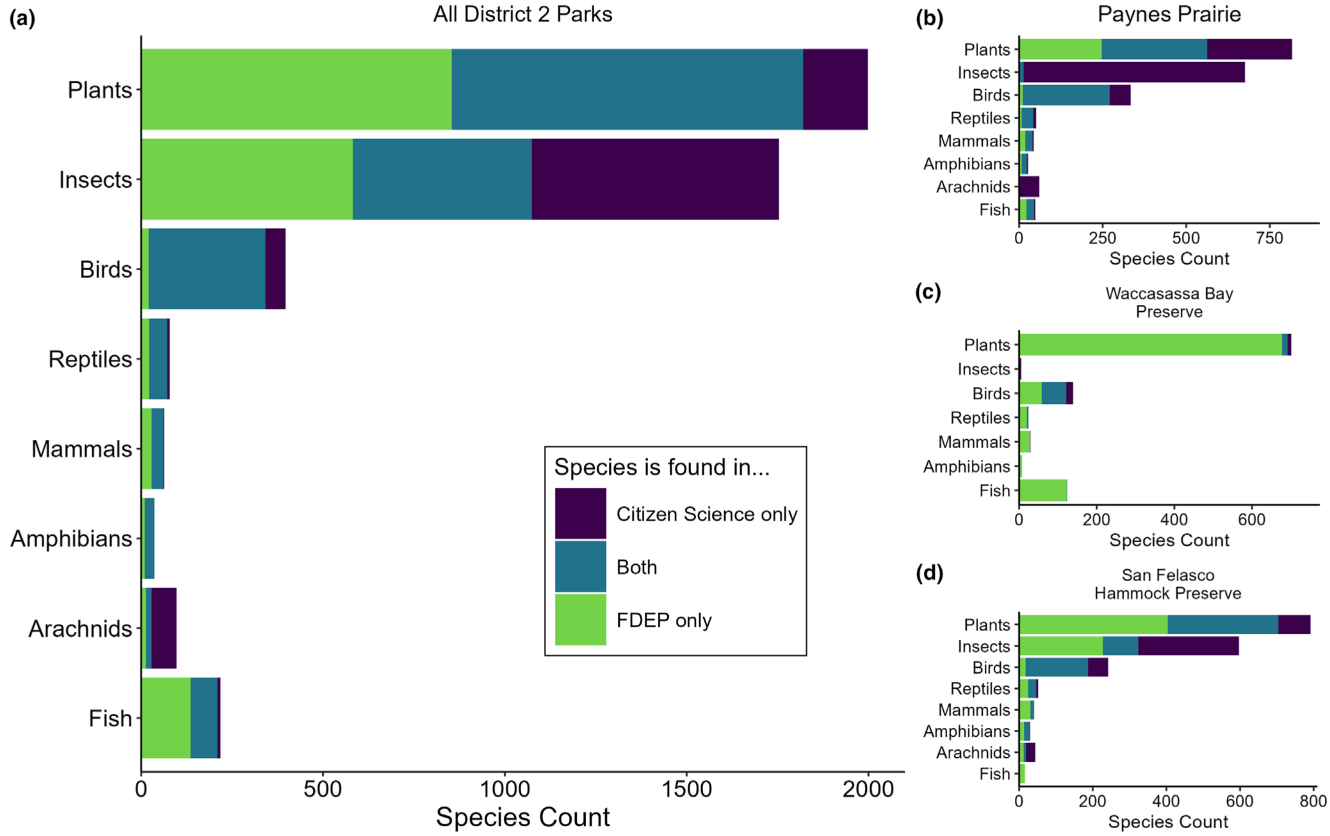

FIGURE 3 The number of species in eight major taxonomic groups documented by FDEP only, citizen science only, or both sources for (a) all 39 parks and (b–d) three specific parks to illustrate variation in citizen science and FDEP contributions to each park.

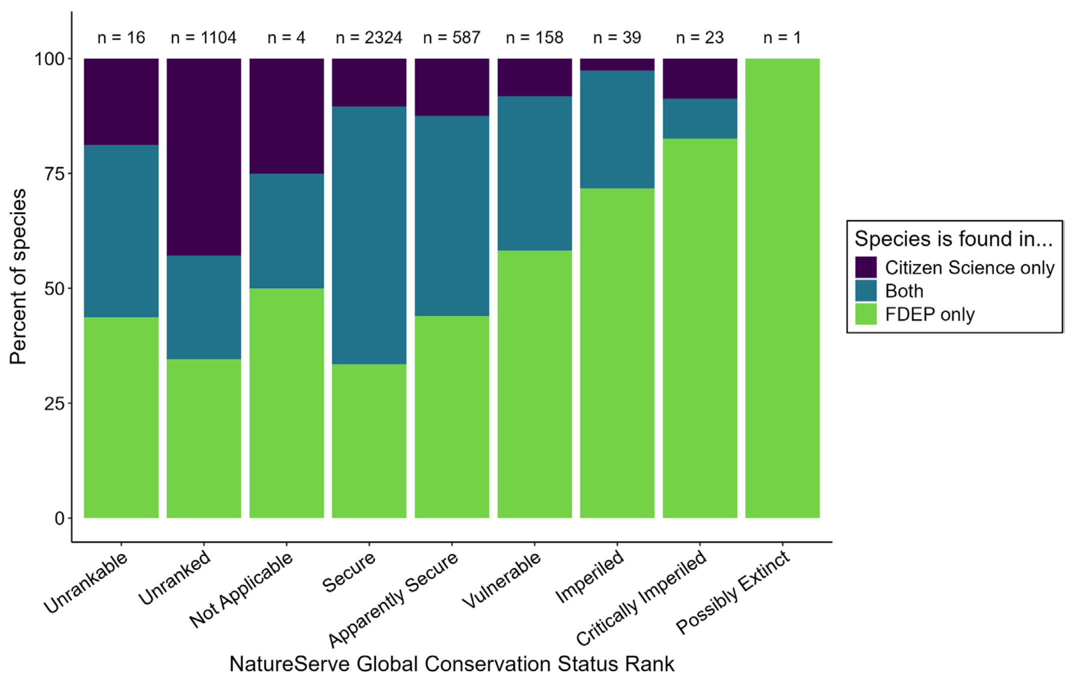

FIGURE 4 Percentage of species across all parks documented by FDEP, citizen science or both categorized according to conservation statuses per NatureServe ($N = 4256$).

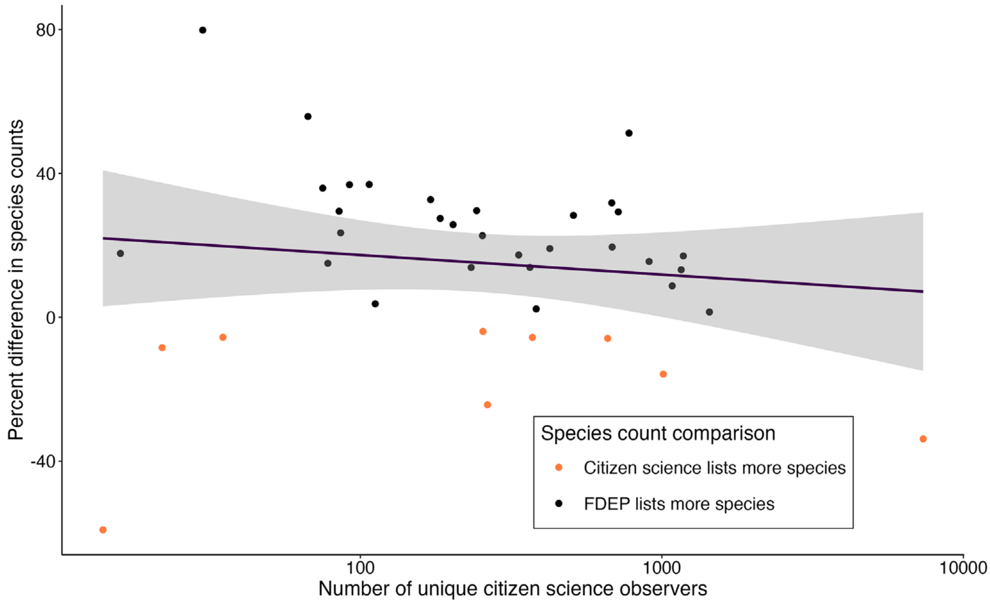

FIGURE 5 The relationship between the per cent difference in species counts from FDEP and citizen science and the number of unique citizen science observers in each park (p-value = 0.447, estimated effect = −2.273 and adjusted $R^2 = -0.010$). Per cent difference is calculated as (number of species documented by FDEP − number of species documented by citizen science)/(number of species documented by FDEP + number of species documented by citizen science) × 100.

contributions of citizen science data among individual parks; certain parks had many of its species listed by FDEP while others had a majority only listed by citizen science. Park-level characteristics including the sampling efforts of citizen science observers did not predict the contribution pattern of citizen science data to the species inventory.

Adopting strategies to incorporate citizen science data into species inventories conducted by government agencies may be increasingly valuable as the amount of available citizen science data increases. eBird participation grows around 20% annually (Cornell University, 2025) and the number of observations on iNaturalist is growing exponentially, roughly doubling annually (Di Cecco et al., 2021). In the parks we studied, the addition of citizen science data is most valuable to improve the completeness of inventories for insects. Previous work has shown that 51% of iNaturalist users with at least 50 observations specialize in plants and insects (Di Cecco et al., 2021). This prioritization of insects, while not necessarily deliberate, helps explain the wealth of insect observations in our citizen science dataset and the high potential for gap filling from iNaturalist data. The value of citizen science data extends beyond insects, however, as specific examples in parks support the capabilities of citizen science to complement agency data by documenting highly visible, common species. For example, in San Felasco Hammock Preserve State Park, citizen science is the only source that documents the wood duck (*Aix sponsa*), a bird we would ordinarily expect to be documented alongside other wetland birds the agency includes in their species inventory. Prior to our study, case studies on specific species or taxonomic groups have supported the potential for citizen science data to complement professional data (Callaghan et al., 2018, 2020; Dimson et al., 2023; Pernat et al., 2021; Roberts et al., 2022). Our research extends the scope of comparison to include all documented biodiversity across multiple sites. With increasing acceptance of citizen science in policies, like the Crowdsourcing and Citizen Science Act (2017), our results highlight the validity of these initiatives, illustrating that citizen science data can indeed fill important taxonomic gaps and complement professional biodiversity monitoring efforts.

We focused on eBird and iNaturalist data to make our results and recommendations widely applicable, given the expansive scope of these datasets. In doing so, we may not have utilized all the available citizen science data. Over 1000 projects exist globally, often on a more structured, smaller scale with narrower taxonomic specificity (SciStarter, 2025). Regionally specific projects could have added more species to our citizen science data set and could be useful in other locations as well. For the parks we studied, large amounts of citizen science data were readily available. However, in regions with limited access, lower participation or more restricted lands, agency-led surveys remain essential (Callaghan et al., 2020). Although our results support the incorporation of citizen science data into government species inventories, it is not meant to be a replacement. Rather, our findings illustrate how citizen science can enhance existing monitoring efforts, especially in areas where data collection by agencies is constrained.

Species inventories can be enhanced by citizen science data through the documentation of species of conservation concern. In our study, citizen science provided the sole documentation of some species with 'Unrankable', 'Unranked', 'Not Applicable', 'Secure', 'Apparently Secure', 'Vulnerable', 'Imperiled' and 'Critically

Imperiled' statuses, but most species in these categories were documented by FDEP. All 'Possibly Extinct' species were documented by FDEP. Although citizen science did not document many species of conservation concern that FDEP did not already document, even single species additions could be valuable to conservation-oriented goals of land management. Despite our results, there remains uncertainty in the value citizen science data can provide species inventories for species of high conservation concern. To protect species with threats linked to location disclosure, iNaturalist obscures the location of observations for these species by randomizing the observation's latitude and longitude within a 0.2×0.2-degree rectangular grid (425 square-kilometres in northern Florida) around the actual location. In our dataset, 1.47% (52 out of 3540 species) of species and 0.74% of observations (383 out of 52,016) are automatically obscured. Because of this, certain observations in our dataset may be falsely attributed to a particular park impacting the utility of citizen science data for documenting these species (iNatHelp, 2023). Citizen science projects that generate data types other than occurrence data may be more appropriate for documenting species threatened with risk of extinction (Gallagher et al., 2024). Our analysis was also limited by the lack of NatureServe statuses for 1206 species in our dataset (from both sources). We speculate that this is because many insects on our list have no NatureServe classification (Brown et al., 2004) with a potentially minor influence of incongruent species names (i.e. NatureServe and iNaturalist use different scientific names for a small number of species).

Throughout our analysis, we encountered other limitations that could be addressed by changes in FDEP reporting and future studies. The methods used to compile the FDEP species lists were unclear and likely varied by park. The taxonomic focus of inventories also appeared to vary by park. For example, while species lists generally included detailed plant inventories, they showed greater variability in the coverage of insects and other arthropods. Additional information on how these lists were generated—such as the survey methods and monitoring effort involved—would enable more comprehensive comparisons with citizen science data. Additionally, for the 39 parks we examined, no single date could be determined to ensure the same data collection time frame for both citizen science and FDEP datasets. FDEP species lists can originate any time after the park was initially acquired. Park acquisition could also predate the conception of eBird (2002) and iNaturalist (2008) creating more time for FDEP data collection than citizen science data collection. With more information on agency collection techniques, future research could investigate how contributions differ on the same timescale. Despite differing time frames, our analyses are done with the maximum amount of data from both sources that reflect the conditions in which either source can be used by practitioners. An important future step in using citizen science data for inventories is to quantify the sampling thresholds at which citizen science data match or exceed agency inventories. We feel this makes our results representative of how citizen science data could be used in species inventories in the near future. We also recommend that future diverse taxonomic comparisons of agency and citizen science data take place at a larger scale. Investigations with more parks may be able to better assess the influence of citizen science observers and observations, park acreage, city population and park visitation on the contribution of citizen science. Furthermore, more comparisons are needed to support and increase confidence in the value of citizen science data.

A primary goal of our research was to investigate the value of incorporating citizen science data into government-conducted species inventories. Our results indicate that significant additions can be made by including citizen science data in species inventories and our research process has allowed us to develop recommendations for how government entities can use such data. First, we recommend using data from iNaturalist and eBird which together have billions of observations that can be downloaded and filtered to generate regionally specific datasets for free. In addition to data availability, for certain groups of species like birds, large numbers of citizen science contributors can increase the documentation of rare species leading to higher species richness documentation by semi-structured citizen science surveys sourced from eBird (Callaghan et al., 2018). To encourage citizen science data generation, we recommend that park managers engage in outreach seeking contributions to park species counts. One method we recommend is hosting bioblitz events. These events can increase the collection of citizen science data at specific parks (Callaghan et al., 2025) and familiarize participants with iNaturalist to encourage continued contributions. With concern for data quality, we recommend using only 'Research Grade' iNaturalist observations and filtering observations from both iNaturalist and eBird to only include observations identified at the genus-species level. 'Research Grade' iNaturalist observations have a genus-species level ID with at least 2/3^{rds} consensus of community identifications and pass the iNaturalist data quality assessment making them the most reliable data produced by the platform (iNatHelp, 2024). While a finer resolution of subspecies data was available, iNaturalist observations are often not identified to subspecies level as this is not a requirement for observations to be 'Research Grade'. Working with genus-species level data is useful for harmonizing the taxonomy from FDEP, iNaturalist and eBird, one of our greatest data management challenges. For further ease of data integration, we recommend that agencies standardize the taxonomy of data collection to conform with the iNaturalist Taxonomy. Our research and recommendations shed new light on how citizen science data can be used for taxonomically diverse species inventories.

4.1 | Management implications

Our main conclusion is that citizen science data can complement species inventories from agency-level data. This conclusion has several implications for management. First, citizen science can help managers detect species of conservation concern or non-native species that might otherwise be missed. For example, bioblitzes complemented National Park Service inventories by documenting previously unrecorded native species (Katzer et al., 2025), likely shifting management priorities. Similarly, one of the main uses of iNaturalist data is documenting range expansions and new records within geopolitical boundaries (Mason, Mesaglio, et al., 2025a). Second, citizen science contributions can fill taxonomic gaps in agency surveys, allowing managers to evaluate ecological communities across a wider range of taxa. In particular, given global insect declines, our results illustrate the potential of citizen science to strengthen insect monitoring in the future (Roy et al., 2024). Third, because citizen science data are collected continuously, they can complement the longer time horizon updates of agency inventories by providing near real-time signals of ecological change (Wyeth et al., 2019). We speculate that this temporal resolution is particularly valuable for detecting shifts in community composition, range expansions or population declines, especially as advanced statistical methods for analysing citizen science data continue to become available. Finally, citizen science data can guide public engagement strategies, for example, parks with low levels of citizen science activity could prioritize outreach events such as bioblitzes (sensu Katzer et al., 2025) to both improve inventories and foster community involvement in stewardship. Taken together, these examples suggest that managers can leverage citizen science to simultaneously enhance long-term monitoring and strengthen connections between agencies and the public.

AUTHOR CONTRIBUTIONS

Samantha K. Lowe, Brittany M. Mason and Corey T. Callaghan conceived the ideas and designed methodology. Samantha K. Lowe and Brittany M. Mason collected the data and analysed the data. Samantha K. Lowe led the writing of the manuscript. Corey T. Callaghan and Nia A. Morales supervised the project. All authors contributed critically to the drafts and gave final approval for publication.

ACKNOWLEDGEMENTS

We wish to acknowledge and thank FDEP, specifically Scott Groves, for providing data and information about Florida state park species inventories consistently throughout the duration of this research. Corey T. Callaghan acknowledges that this research was supported in part by the intramural research program of the U.S. Department of Agriculture, Hatch, FLA-FTL-006297. Additionally, this work is supported in part by the U.S. Department of Agriculture, McIntire-Stennis Program, project award no. FLA-FTL-006659.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.70173.

DATA AVAILABILITY STATEMENT

Data, including our combined FDEP and citizen science dataset, and all relevant code are archived in a Zenodo repository (Lowe et al., 2025; https://doi.org/10.5281/zenodo.17859011).

STATEMENT ON INCLUSION

Our study was based on data from state parks in Florida. To engage relevant stakeholders, our data collection process incorporated the input of FDEP staff in addition to academic researchers from the University of Florida.

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SUPPORTING INFORMATION

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

Figure S1. We conducted an exploratory analysis to assess whether the citizen science data might be inflating the number of rare species observations compared to Florida Department of Environmental Protection (FDEP) data in managed lands.

Figure S2. The percent difference in FDEP and citizen science insect species counts for each park. Percent difference is calculated as (number of insect species documented by FDEP − number of insect species documented by citizen science)/(number of insect species documented by FDEP + number of insect species documented by citizen science) × 100.

Figure S3. The percent difference in FDEP and citizen science plant species counts for each park. Percent difference is calculated as (number of plant species documented by FDEP − number of plant species documented by citizen science)/(number of plant species documented by FDEP + number of plant species documented by citizen science) × 100.

Figure S4. The percent difference in FDEP and citizen science bird species counts for each park. Percent difference is calculated as (number of bird species documented by FDEP − number of bird species documented by citizen science)/(number of bird species documented by FDEP + number of bird species documented by citizen science) × 100.

Figure S5. The percent difference in FDEP and citizen science reptile species counts for each park. Percent difference is calculated as (number of reptile species documented by FDEP − number of reptile species documented by citizen science)/(number of reptile species documented by FDEP + number of reptile species documented by citizen science) × 100.

Figure S6. The percent difference in FDEP and citizen science amphibian species counts for each park. Percent difference is calculated as (number of amphibian species documented by FDEP − number of amphibian species documented by citizen science)/(number of amphibian species documented by FDEP + number of amphibian species documented by citizen science) × 100.

Figure S7. The percent difference in FDEP and citizen science mammal species counts for each park. Percent difference is calculated as (number of mammal species documented by FDEP − number of mammal species documented by citizen science)/(number of mammal species documented by FDEP + number of mammal species documented by citizen science) × 100.

Figure S8. The percent difference in FDEP and citizen science fish species counts for each park. Percent difference is calculated as (number of fish species documented by FDEP − number of fish species documented by citizen science)/(number of fish species documented by FDEP + number of fish species documented by citizen science) × 100.

Figure S9. The percent difference in FDEP and citizen science arachnid species counts for each park. Percent difference is calculated as (number of arachnid species documented by FDEP − number of arachnid species documented by citizen science)/(number of arachnid species documented by FDEP + number of arachnid species documented by citizen science) × 100.

Figure 10. The number of species of plants in 14 classes documented by FDEP only, citizen science only, or both sources. This shows all plants documented in all 39 parks.

Figure S11. The number of species of plants in 12 classes documented by FDEP only, citizen science only, or both sources. This shows all plants documented in all 39 parks after removing plants in classes Magnoliopsida and Liliopsida.

How to cite this article: Lowe, S. K., Mason, B. M., Morales, N. A., & Callaghan, C. T. (2026). Participatory citizen science data complements agency-collected data for species inventories. *Ecological Solutions and Evidence*, *7*, e70173. https://doi.org/10.1002/2688-8319.70173