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A Comparison of Butterfly Diversity Results between iNaturalist and Expert Surveys in Eastern Oklahoma

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Abstract: Ongoing worldwide biodiversity declines and range shifts associated with climate change increase the importance of documenting the current distributions of species to establish baseline data. However, financial and logistical constraints make it impossible for taxonomic experts to conduct thorough surveys in most locations. One popular approach to offset the lack of expert sampling is using community science data collected by the public, curated, and made available for research. These datasets, however, contain different biases than those typically present in data collected through conventional survey practices, often leading to different results. Recent studies have used massive datasets generated over large areas; however, less is known about the results obtained at smaller scales or with more limited sampling intervals. We compared butterfly observations in eastern Oklahoma using a dataset obtained from the popular community science website iNaturalist and one collected during targeted surveys of glade habitats conducted by taxonomic experts. At the county-level scale, the relative abundances of butterfly species correlated well between the glade surveys and the iNaturalist observations, and there was no difference in the relative abundance of different butterfly families between the two survey methods. However, as anticipated, the conventional surveys outperformed the community science data in measuring biodiversity at a smaller geographic scale.

Keywords: local monitoring; biodiversity; Lepidoptera; community science

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Citation: Harman, A.J.; Eori, M.M.; Hoback, W.W. A Comparison of Butterfly Diversity Results between iNaturalist and Expert Surveys in Eastern Oklahoma. *Diversity* **2024**, *16*, 515. https://doi.org/10.3390/d16090515

Academic Editor: Luc Legal

Received: 20 July 2024
Revised: 8 August 2024
Accepted: 13 August 2024
Published: 27 August 2024

1. Introduction

Community science, the utilization of data collected by the general public, is a form of collaboration between community members and scientists [1,2]. It is becoming increasingly popular as a tool to monitor species distributions and abundances for a variety of taxa, especially because of growing concerns about biodiversity losses [1,3]. The benefits of community science are clear, including cost-effectiveness and the potential for long-term and large-scale (e.g., geographic) data collection [4,5]. The data obtained through community science can also offset the decline in amateur natural history observations and collections [6]. Scientists can potentially utilize thousands of datapoints collected by hundreds of people across broad geographic areas, which would otherwise be logistically impossible. Community science projects can also connect people with nature, increasing their investment in conservation efforts [7].

However, because of the reliance on volunteers and the more relaxed submission guidelines that are commonly associated with community science data collection, there are many potential biases that can occur with community science datasets [8]. For example, Courter et al. [9] found that phenology studies utilizing community science data were affected by "weekend bias": the fact that far more observations were made on weekends when most people are not working compared to weekdays when they are in school or at work. Spatial bias is also common, as locations close to high concentrations of people get much more sampling coverage than locations further away from urban areas [10].

Despite known data biases, community science has made novel contributions to the field of entomology research. Citizen science has led to increased knowledge about the monarch butterfly, *Danaus plexippus*, including estimation of population sizes [11,12], determining migration routes [13–15], and documenting larval parasitism by tachinid flies [16,17]. Community scientists have supported entomology research across broad geographical areas, leading to the discovery of disjunct emergences of periodical cicadas (*Magicicada* spp.) in the eastern United States [18], increased knowledge of ant diversity in the United States [19], and the characterization of the global invasion history of *Pieris rapae*, a widely introduced agricultural pest [20].

Community science not only provides research opportunities for scientists but can provide educational benefits for participants as well. From this perspective, positive outcomes from community science collaborations include community education, improved ecological literacy, and the acquisition of datasets with applied conservation value [2,17]. Research has shown that participation in community science can also increase science knowledge [21–25] and participation in conservation activities [22,26].

Among insects, Lepidoptera is one of the most popular taxa, and community science data are regularly generated for this group [27,28]. With their large, brightly colored, diurnal, and relatively easy-to-identify species, butterflies are among the easiest insect groups for amateur naturalists to notice, photograph, and identify [29]. In contrast to easily recognizable species, butterflies in the family Hesperiidae, known as skippers, can be challenging to identify, even for experts [30]. Difficulty with identification can lead to underestimation of these taxa [31]. Other factors that can influence which butterflies are reported on iNaturalist include size, attraction to cultivated landscapes and garden plants, and the number of generations a species produces per year.

Butterflies were one of the focal taxa in a larger study to document the biodiversity of glades located in the Ozark Mountains in eastern Oklahoma. Glade habitat is defined as an open area within a forested landscape that has sparse vegetation because of rocky or gravelly shallow soils. Glades support a unique assemblage of plants and animals adapted to small grassland patches surrounded by forest. These habitats are threatened in the United States, including in Oklahoma, because of fire suppression that allows glades to be invaded by woody vegetation and by off-road vehicle recreational use.

We sought to compare results from our targeted surveys with the diversity of butterflies reported on iNaturalist, both at the county level and within individual nature preserves, to examine known biases associated with iNaturalist data compared to structured formal surveys. We expected that large, easy-to-identify groups of butterflies such as swallowtails (Papilionidae) would be proportionally more abundant in the iNaturalist dataset, while smaller, harder-to-identify groups such as skippers (Hesperiidae) would be proportionally more abundant in our survey dataset.

2. Materials and Method

2.1. Glade Butterfly Surveys

Butterfly surveys were conducted at 19 transects across nine glades in three nature preserves: Cherokee Wildlife Management Area (WMA), Cookson Hills WMA, and the J.T. Nickel Family Nature & Wildlife Preserve. These protected areas are within the Cherokee and Adair counties in eastern Oklahoma and are at the western edge of the Ozark Mountains (Figure 1). The focus of these surveys was to document butterfly diversity in glades, which are isolated pockets of grassland that occur in areas with shallow soils and exposed bedrock, surrounded by forest. While our surveys were glade-focused, the small size of these glades ensured that we were always near a grassland/forest ecotone. Additionally, many glades are near ephemeral springs, streams, and pools that provide small patches of wetland habitat.

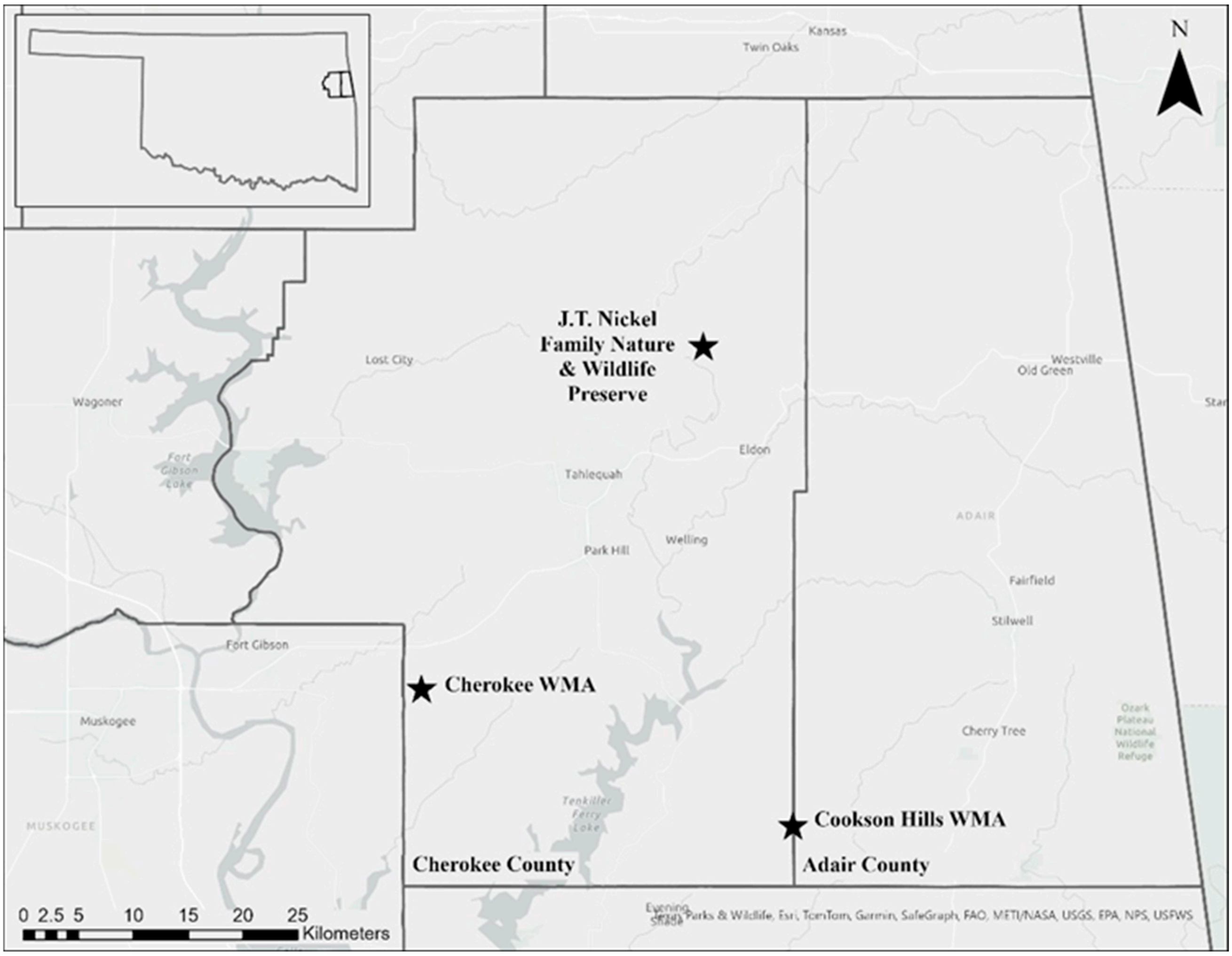

Figure 1. Locations of the three nature preserves where butterfly surveys were conducted in Cherokee and Adair Counties in eastern Oklahoma.

The surveys were conducted using a modified Pollard transect, in which the surveyor slowly walks a fixed route of 100 m and records the observed butterflies [32,33]. The starting points of each transect were randomly generated, with the direction of the transect intentionally placed through the glade. Because of the narrow and curved nature of the glades used in this study, the transect direction usually changed at the midpoint, ensuring that the transect remained in the glade habitat and avoided the surrounding forest. During transect walks, all butterflies to the sides and in front of the surveyor were identified and counted [34]. Butterflies were spotted with the naked eye, but binoculars and an aerial insect net were occasionally utilized to confirm identifications and collect voucher specimens of unexpected species. AJH originally learned to identify butterflies using the *Kaufman Field Guide to Butterflies of North America* [35]. The *Catalog of the Butterflies of the United States and Canada* [36] was consulted for taxonomic changes.

Surveys were performed three times at each transect in 2023, once each in the spring (14–22 April), summer (6–9 June), and fall (16–23 September), to capture the butterfly activity throughout the season. Surveys were conducted between the hours of 0900 and 1600 when conditions were sunny and wind speeds were <10 km/h. In Oklahoma, butterfly species can be single-brooded, with many of these species only found in the spring or summer, or double-brooded, with species present across much of the year [35].

2.2. iNaturalist Data Acquisition

iNaturalist observations of butterflies from Cherokee and Adair Counties in 2023 were compared to the survey results. We used species-level observations, except for two types of skippers (Family Hesperiidae). The duskywings, *Erynnis* sp., and cloudywings, *Thorybes* sp., were identified to genus because these genera can be difficult to identify to species from photographs. Observations posted to iNaturalist by the first author, AJH, were excluded from the analysis. Identifications of unexpected or challenging-to-identify butterflies posted to iNaturalist were confirmed or corrected as needed by AJH in order to avoid misleading results as a result of incorrect identifications [30]. Only one research-grade observation needed correcting, but there are multiple identifiers, including AJH, who regularly review butterfly records in Oklahoma, so most observations that were originally misidentified when they were submitted had previously been corrected.

2.3. Analyses

The relative abundances of butterfly species were compared between the glade surveys and iNaturalist datasets by taking the number of times a species was observed and dividing it by the total number of butterfly observations (238 for iNaturalist and 709 for glade surveys). The relationship between the relative abundances from the two survey types was analyzed using a linear regression. We also sorted the butterflies by family to compare the mean relative abundances of species within each family using an ANOVA. In both these analyses, the entire datasets from iNaturalist and the glade surveys were utilized. To test the effect of timing and scale, we calculated Shannon diversity indices for each of the sampling periods, including spring (March–May), summer (June–August) and fall (September–November) for each of the three preserves assessed by experts. The iNaturalist data were divided by the observation period, and survey data were compared by using Student's *t*-tests. For this analysis, the data were divided into subsets by nature preserve and time period (butterfly observations n = 709 for glades, n = 58 for iNaturalist).

3. Results

In 2023, there were 238 observations of butterflies posted to iNaturalist from Cherokee and Adair Counties. In comparison, we recorded 709 butterfly observations during our three survey periods. The iNaturalist observations were posted by 37 observers, with the highest number of observations made at two areas with public access: Sequoyah State Park (30) and the J.T. Nickel Family Nature & Wildlife Preserve (26). While community science observations are often highly concentrated around cities [10], this was not the case in eastern Oklahoma. Tahlequah, the largest city in Cherokee and Adair Counties (with 16,828 residents as of 2022), only had eight submitted butterfly records in 2023.

Despite the disparity in the number of individuals observed or reported, the number of species was similar between the survey types, with iNaturalist observations documenting 52 species and our surveys documenting 55. Among these, each survey type had about 20% unique species, resulting in a total of 65 species recorded in these counties in 2023 (Table 1). Unique species tended to be those at the edge of their range (i.e., *Eurytides marcellus*) or species with specific habitat requirements (i.e., *Hesperia metea*, *Megathymus yuccae*), but this was not always the case and there were some common, widespread species that were only detected by one method (i.e., *Asterocampa clyton*, *Dione vanillae*). The 65 species we detected represent more than half of the 119 butterfly species recorded from Cherokee and Adair counties and nearly one-third of the 206 species recorded in Oklahoma [37]. All five families were recorded by both methods, with Nymphalidae having the most species (23) and Hesperiidae (17) having the second most species.

Table 1. A list of all the species detected during 2023, including the number of observations posted to iNaturalist and the number of detections recorded during glade surveys.

Family	Species	iNaturalist	Transects	Total
Papilionidae	*Battus philenor*	3	37	40
	Eurytides marcellus	0	1	1
	Papilio cresphontes	1	0	1
	Papilio glaucus	13	16	29
	Papilio polyxenes	6	3	9
	Papilio troilus	6	20	26
Pieridae	*Abaeis mexicana*	1	8	9
	Abaeis nicippe	2	17	19
	Anthocharis midea	1	9	10
	Colias eurytheme	6	39	45
	Colias philodice	1	2	3
	Nathalis iole	6	45	51
	Phoebis sennae	1	5	6
	Pontia protodice	4	4	8
	Pyrisitia lisa	2	19	21
	Zerene cesonia	0	3	3
Lycaenidae	*Callophrys gryneus*	0	10	10
	Calycopis cecrops	0	6	6
	Celastrina ladon	0	1	1
	Celastrina neglecta	1	0	1
	Cupido comyntas	8	70	78
	Phaeostrymon alcestis	3	1	4
	Satyrium calanus	3	5	8
	Satyrium titus	2	0	2
	Strymon melinus	2	5	7
Nymphalidae	*Anaea andria*	8	22	30
	Asterocampa celtis	10	2	12
	Asterocampa clyton	1	0	1
	Cercyonis pegala	0	1	1
	Chlosyne gorgone	2	11	13
	Chlosyne nycteis	10	3	13
	Cyllopsis gemma	2	14	16
	Danaus plexippus	2	4	6
	Dione vanillae	6	0	6
	Euptoieta claudia	11	37	48
	Hermeuptychia sosybius	3	2	5
	Junonia coenia	12	51	63
	Lethe anthedon	2	0	2
	Lethe portlandia	1	0	1
	Libytheana carinenta	0	8	8
	Megisto cymela	1	4	5
	Phyciodes tharos	5	24	29
	Polygonia interrogationis	6	5	11
	Speyeria cybele	5	20	25
	Speyeria diana	8	1	9
	Vanessa atalanta	3	1	4
	Vanessa cardui	0	6	6
	Vanessa virginiensis	4	7	11
Hesperiidae	*Amblyscirtes belli*	2	1	3
	Amblyscirtes linda	2	0	2
	Atalopedes huron	4	7	11
	Atrytonopsis hianna	0	3	3
	Burnsius communis	0	10	10
	Epargyreus clarus	7	28	35
	Erynnis sp.	29	79	108
	Euphyes vestris	2	1	3

Table 1. *Cont.*

Family	Species	iNaturalist	Transects	Total
	Hesperia metea	0	1	1
	Hylephila phyleus	6	14	20
	Megathymus yuccae	0	2	2
	Pholisora catullus	1	1	2
	Polites origenes	0	1	1
	Problema byssus	3	0	3
	Staphylus hayhurstii	1	0	1
	Thorybes lyciades	4	5	9
	Thorybes sp.	3	7	10

The Shannon diversity index for the glade transect (3.55) and county-level iNaturalist reports (3.36) were similar when all data were included. As expected, season and location affected diversity estimates for the transects and for iNaturalist data reported from the preserves (Table 2). These results were influenced by the number of observations (N = 709 for transect sampling and 58 for iNaturalist observations posted from the preserves). Surprisingly, two survey periods, spring at the Nickel Preserve and summer at the Cherokee Preserve, had higher Shannon diversity for the iNaturalist reports compared to diversity observed by scientists conducting transect surveys (Table 2). No observations of butterflies were reported from the nature preserves in fall.

Table 2. Shannon diversity indices for nature preserves by season, comparing glade transects and iNaturalist data.

Location	Season	iNaturalist Data	Survey Data
Cookson	Spring	2.1	2.96
	Summer	0.69	3.08
	Fall	0	2.62
Nickel	Spring	2.45	1.43
	Summer	1.04	2.35
	Fall	0	1.64
Cherokee	Spring	0	2.01
	Summer	2.87	2.24
	Fall	0	1.07
Overall Mean		1.02 ± 1.168	2.16 ± 0.685

The relative abundance of species from both survey methods was positively correlated (r^2 = 0.48, slope = 0.84) (Figure 2). The most notable outlier was the eastern tailed-blue, *Cupido comyntas*, which made up only 3.4% of iNaturalist observations but accounted for 9.9% of the butterflies observed during the glade surveys. Although three families had higher relative abundance with iNaturalist data and two with our glade surveys (Figure 3), there were no statistically significant differences. Thus, surprisingly, there were no significant biases for any butterfly families reported to iNaturalist.

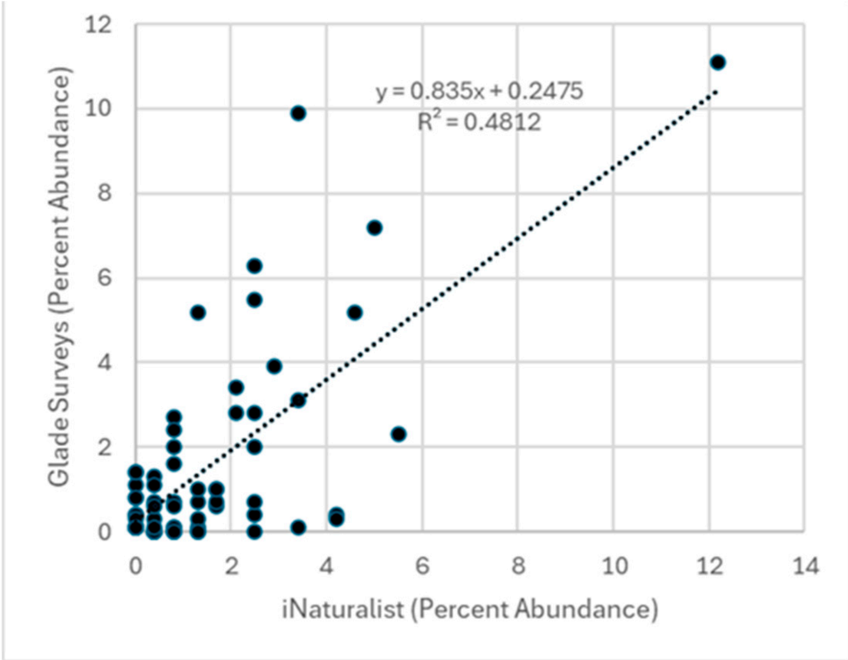

Figure 2. The relative abundances of species based on iNaturalist observations compared to the relative abundances of species detected during glade surveys.

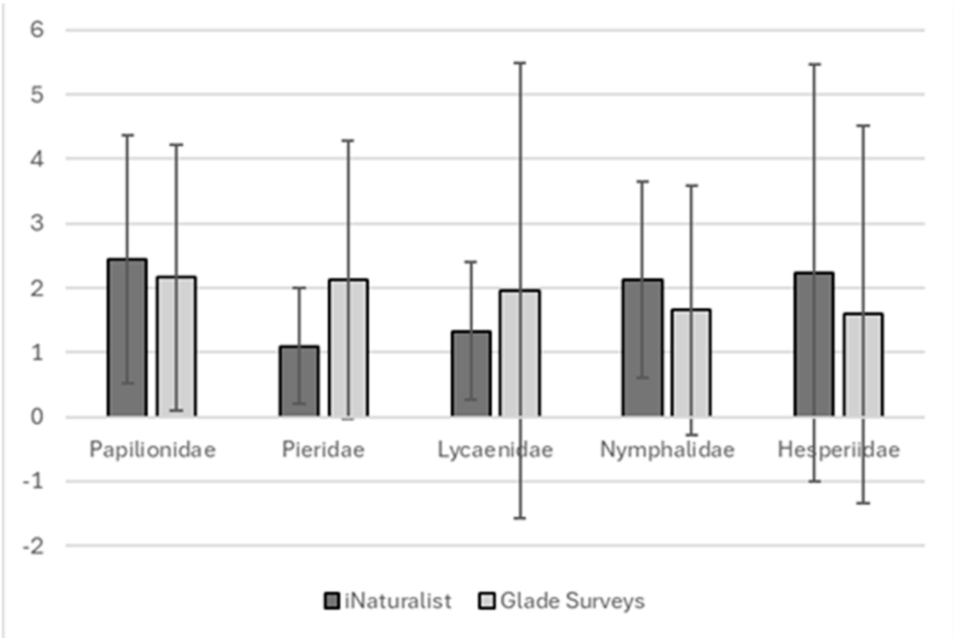

Figure 3. The mean (±1 standard deviation) relative abundance of species in each butterfly family reported in Cherokee and Adair counties in 2023, as documented by iNaturalist and conventional transect surveys.

4. Discussion

The observed difference in number of individuals documented by each survey type was expected. Unlike more taxon-specific community science databases, such as eBird, the verification of observations on iNaturalist relies entirely on the submission of photographs or audio recordings of the organism being observed [38]. Given the broad taxonomic and geographic scope of iNaturalist, encompassing all living organisms worldwide, this verification process is essential to ensure that identifications are as accurate as possible [39].

However, unlike in databases that focus on specific taxonomic groups where visual identifications are commonly accepted, users do not include every organism that they encounter while in the field. As a result, an observer is far more likely to try to document as many species of butterflies as possible, rather than documenting each individual they photograph [40] or observe. In contrast, transect surveys often focus on abundance as well as species diversity to assess a community, and thus, species are recorded in numbers that reflect their abundance during observations.

While a single iNaturalist observation is not quantifiable beyond the organism that is photographed, as observations accumulate, more abundant species are likely to be observed more frequently than rarer species, and so the number of observations of each species may approach their relative abundance compared to the total number of individuals observed within the broader taxon [41]. We saw this trend when comparing the relative abundances of different species, which were positively correlated (Figure 2). This indicated that the species that were more abundant in the glades also tended to be the species most frequently reported on iNaturalist. An interesting difference was observed with the eastern tailed-blue, *Cupido comyntas*, which was found nearly three times more frequently during glade surveys than it was reported on iNaturalist. This was a surprising result, as the larvae of this species feed primarily on clover (*Trifolium* spp.), making it one of the more common backyard butterflies throughout eastern Oklahoma [42]. However, *C. comyntas* flies low to the ground and can be easy to overlook, causing it to be missed by casual observers. In addition, it may be more challenging to photograph because of its small size and behavior of spending short periods nectaring. In addition, blues tend to not be territorial and will fly away when spooked by an observer or photographer. In contrast, male skippers will establish territories and return to perches when startled, increasing opportunities for photographs. When considering the use of records on iNaturalist and other community science sources where photographic evidence is required, species or sex differences in behavior should be considered and further researched.

When comparing the relative abundances of species in different families, the results countered our expectations. We anticipated that the large, showy swallowtail butterflies (Papilionidae) would be most highly represented in the iNaturalist dataset, while the small, quick-flying skippers (Hesperiidae) would make up a higher proportion of the survey results. However, none of the five butterfly families showed significant differences in proportional abundance between the datasets. This suggests that for Oklahoma butterflies, there was little to no taxonomic bias between the two survey methods. Similar results were observed in a study that compared community science data and collection data [38].

Surprisingly, the Pieridae, the whites, sulphurs, and orangetips, showed the largest discrepancy in this study, being nearly twice as proportionally abundant in the glade surveys as reported on iNaturalist. A similar underrepresentation of Pieridae was recently found in a study comparing the results of iNaturalist with those of eButterfly, where 9 out of the 10 most underrepresented species on iNaturalist were pierids [43]. This, like the underreporting of blues, is potentially a result of their flight patterns, as some species such as the falcate orangetip, *Anthocharis midea*, are known to be challenging to photograph because they only stop to nectar for brief periods of time. Given that iNaturalist is photo-based, even if an observer sees dozens of *A. midea*, obtaining a good-quality photograph may be difficult. This trend should be further tested in future studies, as wary and active insects are likely to be underrepresented in iNaturalist datasets compared to more sessile species.

Comparison of diversity estimates for monthly observations reported to iNaturalist from the nature preserves also revealed an unexpected pattern. During this study's time period, 58 records were reported to iNaturalist from the areas also examined in glade transects. The iNaturalist data estimated higher butterfly diversity for two preserves, one in spring and one in summer (Table 2). This result is explained by the influence of evenness in the data (our transects include abundance for all species) and a greater time window for iNaturalist observers (our sampling occurred over one or two days per preserve while we compared iNaturalist observations for a period of about six weeks). A more surprising result was that no butterfly observations were reported on iNaturalist from any preserve in the fall. Temperatures in Oklahoma are often near 38 °C, ticks and biting mosquitoes are common, and no butterfly species are exclusive to the fall. Thus, these results are likely influenced by the absence of unique species opportunities and by outdoor conditions that make recreation and nature watching less appealing. This potential bias has not been previously reported to our knowledge and should be further investigated when considering the use of community science data.

While the points discussed above would suggest that iNaturalist data can successfully be utilized instead of conventional survey methods to assess butterfly biodiversity, this is most applicable at larger spatial and temporal scales. When examining diversity metrics at the county level (often used to document distribution and diversity), we see that iNaturalist data and the glades surveys produce very similar results. The iNaturalist data show slightly higher diversity despite having three fewer species, which is a result of the higher evenness of the iNaturalist data. The typical observer does not document each individual of a common species that they find [44]. However, when examining the different nature preserves and survey periods individually, conventional survey techniques produce substantially higher diversity measures than iNaturalist data most of the time. This result can be attributed to a lack of observers at individual locations. Additionally, we found a substantial temporal effect associated with weather conditions and lack of new species emergence. As a rule, it is likely that fewer people using iNaturalist results in fewer observations and stronger biases to different species, trends that should be further investigated.

5. Conclusions

To summarize, there are many potential factors that can influence the abundance of species reported to community science projects relative to their natural abundance. However, with enough observations, community science data can reflect the relative abundances of species detected during formal surveys. This pattern is likely influenced by having a relatively large number of observers. In 2023, 37 observers posted pictures of butterflies found within the counties we examined, which helped to balance out individual observation biases. However, at smaller scales, community science data became less representative of conventional survey data and instead are likely to emphasize observer biases and the influence of weather and likelihood of observing novel species. For example, the J.T. Nickel Preserve is closer to a major city than either of the preserve areas, has better roads, and has a visitor center with a pollinator garden. It had substantially more iNaturalist observations than the other preserves, except in the fall, when there were no recorded butterfly observations at any preserve. Conventional surveys conducted by taxonomic experts will likely document biodiversity more thoroughly in a single state park, wildlife management area, or other preserve than community science data in all but the most popular nature preserves. While both conventional surveys and community science data have limits, both can be useful in documenting local biodiversity, especially for charismatic taxa and easily identifiable taxa.

Author Contributions: Conceptualization, A.J.H. and W.W.H.; Methodology, A.J.H. and M.M.E.; Software, A.J.H. and M.M.E.; Analysis, A.J.H.; Investigation, A.J.H. and M.M.E.; Resources, W.W.H.; Data Curation, A.J.H.; Writing—Original Draft Preparation, A.J.H.; Writing—Review and Editing, W.W.H.; Supervision, W.W.H.; Project Administration, W.W.H.; Funding Acquisition, W.W.H. All authors have read and agreed to the published version of the manuscript.

Funding: Funding was provided through the Oklahoma Department of Wildlife Conservation grant number F22AF02332 and Hatch Project accession number 1019561 from the USDA National Institute of Food and Agriculture. Additional support was provided by the Neustadt-Sarkey professorship to W.W.H.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Data is not publicly available to protect sensitive species and their habitats.

Acknowledgments: We would like to acknowledge everyone who helped with data collection in the field: Katharine Miller, Guner Womack, Emerson Harman, and Felipe Crepaldi Alves. We would also like to thank the Oklahoma Department of Wildlife Conservation, The Nature Conservancy, Oklahoma Cooperative Fish and Wildlife Research Unit, and Courtney Duchardt and Brian Murray.

Conflicts of Interest: The authors declare no conflicts of interest.

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