



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*

Kyle D. Kittelberger^{1*}, Solomon V. Hendrix² and Çağan Hakkı Şekercioğlu^{1,3}

¹School of Biological Sciences, University of Utah, Salt Lake City, UT, United States, ²College of Agriculture and Natural Resources, University of Delaware, Newark, DE, United States, ³Department of Molecular Biology and Genetics, Koç University, Istanbul, Turkey

OPEN ACCESS

Edited by:

Piotr Tryjanowski,
Poznan University of Life Sciences,
Poland

Reviewed by:

Reuven Yosef,
Ben-Gurion University of the Negev,
Israel
Peter Mikula,
Academy of Sciences of the Czech
Republic (ASCR), Czechia

*Correspondence:

Kyle D. Kittelberger
kyle.kittelberger@utah.edu

Specialty section:

This article was submitted to
Conservation and
Restoration Ecology,
a section of the journal
Frontiers in Environmental Science

Received: 16 May 2021

Accepted: 19 July 2021

Published: 27 August 2021

Citation:

Kittelberger KD, Hendrix SV and
Şekercioğlu ÇH (2021) 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.
Front. Environ. Sci. 9:710396.
doi: 10.3389/fenvs.2021.710396

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 We have compiled a comprehensive summary of citizen science contributions—published and unpublished—to the understanding of hopper diversity, finding over fifty previously unpublished country and state records as well as dozens of undescribed and potentially unpublished species.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 understudied 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 Auchenorrhyncha 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
<i>Lepyronia angulifera</i> Uhler, 1876	State record (GA, NC, NY, MI, VT)	Hamilton, 2012	BugGuide
<i>Clastoptera octonotata</i> Hamilton, 2015	New species (SC, NC)	Hamilton, 2015	BugGuide
<i>Balclutha rubrostriata</i> Melichar, 1903	Country record (USA) ^{INT}	Zahniser et al., 2010; Carlson et al., 2012	BugGuide
<i>Erasmoneura atra</i> Johnson, 1935	State record (NH)	Chandler and Hamilton, 2017	BugGuide
<i>Eupteryx atropunctata</i> Goeze, 1778	State record (NH) ^{INT}	Chandler and Hamilton, 2017	BugGuide
<i>Eupteryx decemnotata</i> Rey, 1891	State records (NC, NJ, NM, UT) ^{INT}	Ciafré and Barringer, 2017; Tasi and Lucky, 2020	BugGuide, Hoppers of NC
<i>Empoasca kittelbergeri</i> ^a Chandler and Hamilton, 2017	New species (NH)	Chandler and Hamilton, 2017	BugGuide
<i>Empoasca murrayi</i> ^a Chandler and Hamilton, 2017	New species (MA, NH)	Chandler and Hamilton, 2017	BugGuide
<i>Hebata zanclus</i> Hamilton and Langor, 1987	State record (VT)	Chandler and Hamilton, 2017	BugGuide
<i>Hishimonus sellatus</i> Uhler, 1896	Country record (USA) ^{INT}	Hamilton, 2011	BugGuide
<i>lassus lanio</i> Linnaeus, 1761	Country record (CAN) ^{INT}	Hamilton, 2011; Carlson et al., 2012	BugGuide
<i>Tremulicercus fulgidus</i> Fabricius, 1775	Country record (USA) ^{INT}	Carlson et al., 2012	BugGuide
<i>Macropsis infuscata</i> Sahlberg, 1871	Country record (CAN) ^{INT}	Hamilton, 2011	BugGuide
<i>Oncopsis flavicollis</i> Linnaeus, 1761	Country record (CAN) ^{INT}	Hamilton, 2011	BugGuide
<i>Pagaronia minor</i> Anufriev, 1970	Country record (USA) ^{INT}	Hamilton, 2011	BugGuide
<i>Hebetica sylviae</i> McKamey and Sullivan-Beckers, 2019	New species (KY)	McKamey and Sullivan-Beckers, 2019	Other
<i>Asarcopus palmarum</i> Horváth 1921	State record (TX) ^{INT}	Leavengood et al., 2017 ^b	BugGuide
<i>Haplaxius ovatus</i> Ball, 1933	State record (FL)	Wheeler and Wilson, 2014	BugGuide

^aThese species are currently unplaced within the tribe *Empoasini*, as they were not treated in the latest revision of the tribe (Xu et al., 2021), which redefined its component genera.

^bThis 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 neotenus 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 Auchenorrhynchoologists. The small number of

references to citizen science sites in hopper publications may also be a result of the small number of Auchenorrhynchoologists 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.

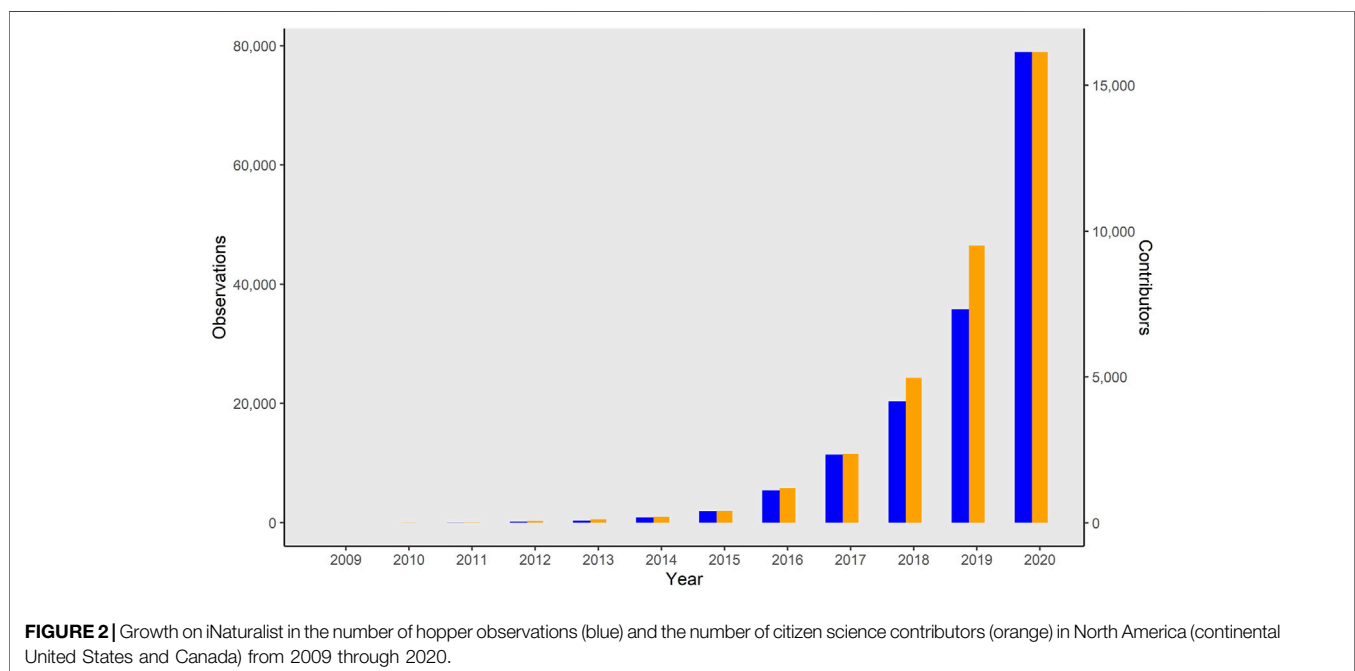
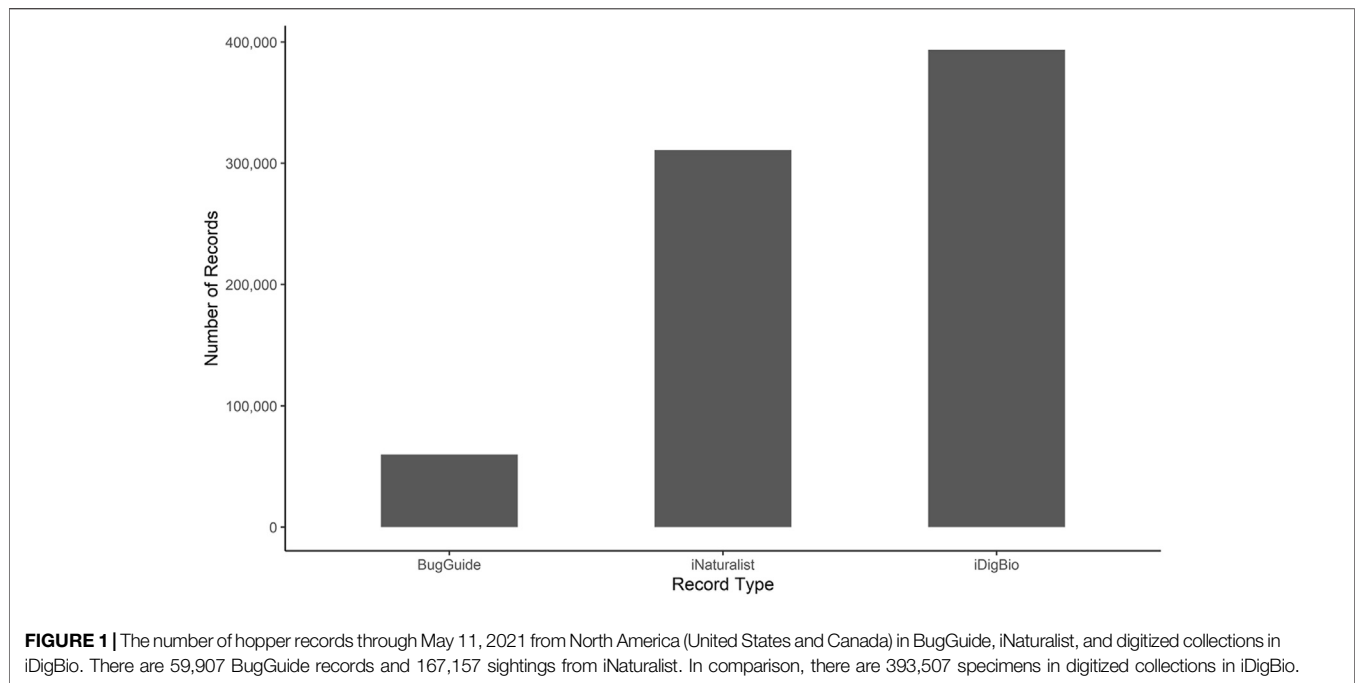
BugGuide and iNaturalist

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 coleopratus*; **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.



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

^aThere 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.

^bAccording 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.

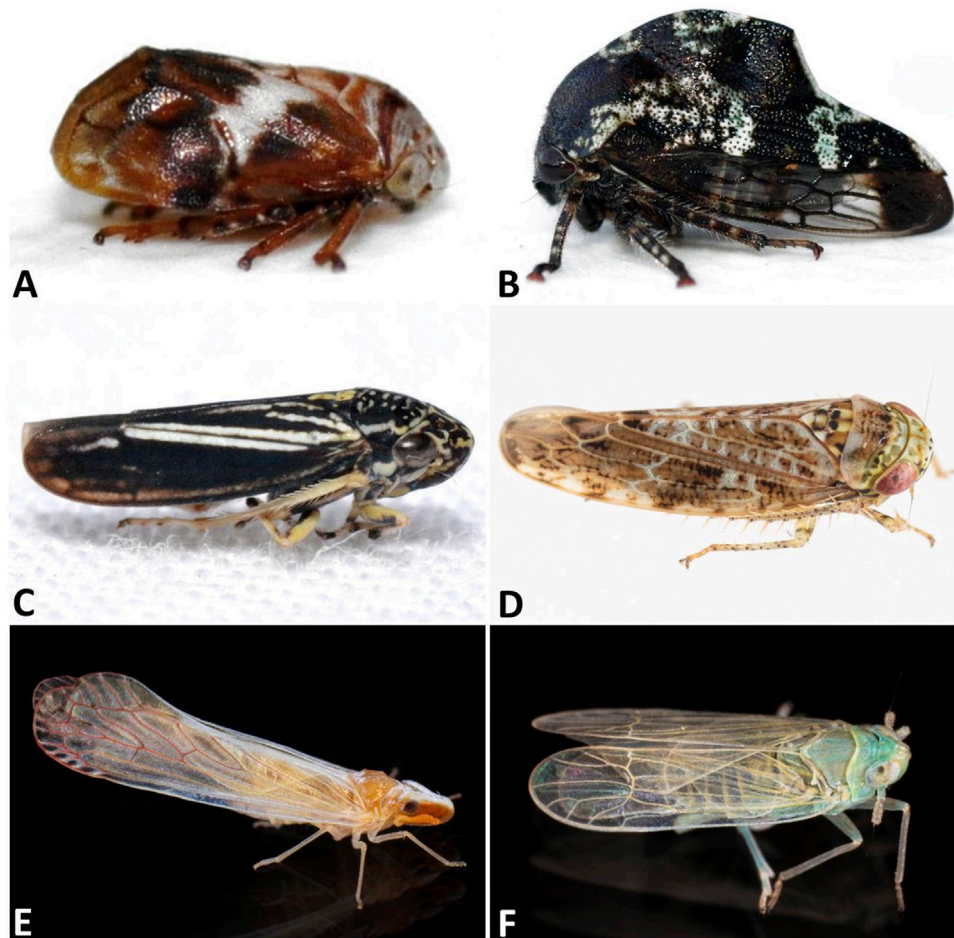


FIGURE 3 | Noteworthy hopper species from continental North America that are mentioned in this study. **(A)** *Clastoptera octonotata* Hamilton, 2015- a spittlebug that was recently described and documented based on citizen science contributions (**Table 1**); **(B)** *Telamona stephani* Wallace, 2018- 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 (**Supplementary 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**).

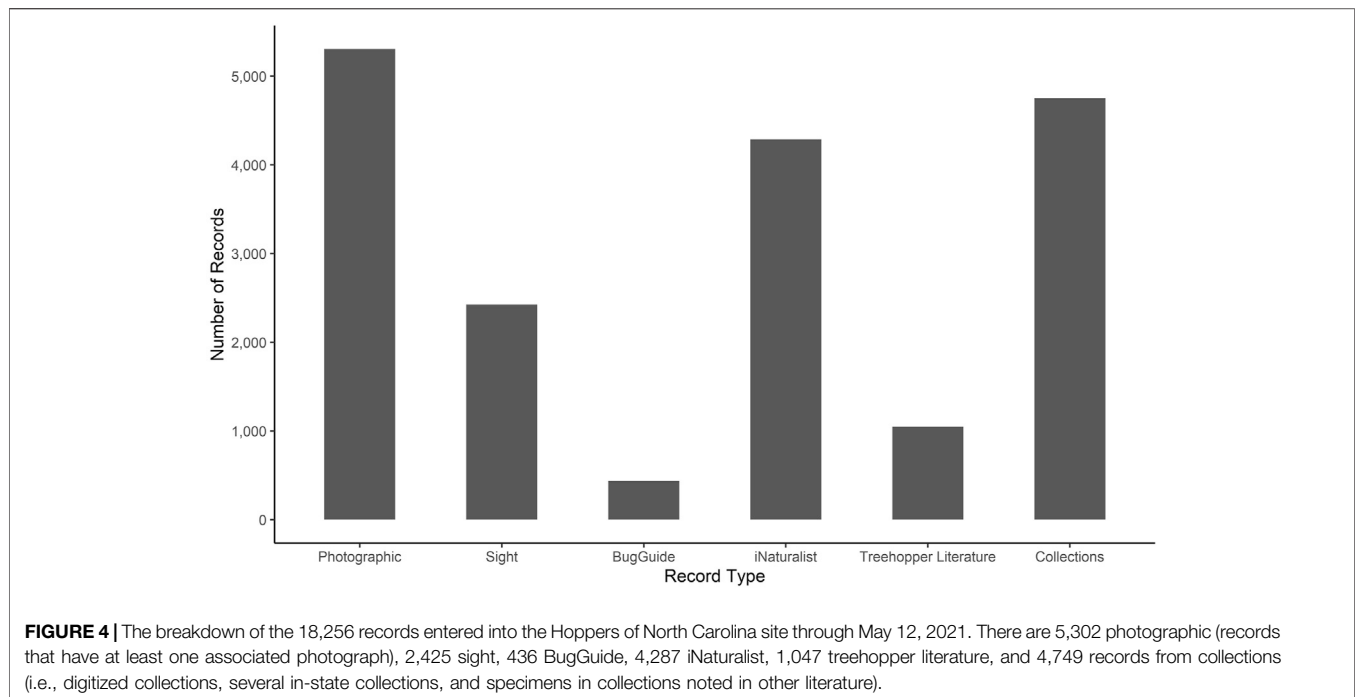
Of the 836 profile pages, 796 represent species reported from within the state. There are 34 profiles that consist of genus-level entries or species complexes for taxa that contain species that are extremely challenging to distinguish or impossible to identify from a picture alone, requiring additional 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 (**Supplementary Table 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



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 colosiasiae* 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 Typhlocybina 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.

FUNDING

The North Carolina Biodiversity Project and the Parsons Family Fund from Dartmouth College provided funding to support various stages of the Hoppers of North Carolina project. We are also grateful to the University of Utah Environmental Studies Graduate Fellowship Fund,

the University of Utah Global Change and Sustainability Center, and Barbara Watkins for their support.

ACKNOWLEDGMENTS

We would like to thank Tom Howard with North Carolina State Parks for all of his assistance as website administrator for the *Hoppers of North Carolina* website as well as the other NCBP sites. This site would not have been possible without Tom's assistance. He has put countless thousands of hours into behind-the-scenes work ranging from coding, ensuring that the site runs smoothly and making the design and function of the site a reality. This project would also not have been as successful without the assistance from Brian Bockhahn, also with the North Carolina State Parks, who has been a part of this project since its conception as an associate project manager and has assisted with searching for hoppers across North Carolina. We would also like to thank the other members of the North Carolina Biodiversity Project for their support and contributions, especially Steve Hall, who came up with the idea for the project, along with Mark Shields and Jim Petranka for submitting hopper records, and J. Bo Sullivan for collecting, pinning, photographing, and dissecting many specimens. Special

thanks to Bob Blinn who graciously provided access to specimens at the NC State Insect Museum. We thank the North Carolina Museum of Natural Science. We also thank the various researchers in the Auchenorrhyncha field we have corresponded with over the years for their assistance, guidance, and input on species identifications, their help with access to publications, and the examination of specimens we have collected. These instrumental researchers include Charles Bartlett, Mark Rothschild, Matthew Wallace, Chris Dietrich, Joel Kits, James Zahniser, Lew Deitz, Vinton Thompson, and Andy Hamilton. And finally, we would like to thank the countless number of citizen scientist contributors on BugGuide, iNaturalist, and Hoppers of North Carolina for their enthusiasm with documenting the natural world. The authors have enjoyed interacting with so many people on these various platforms.

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>.

REFERENCES

- Abolafya, M., Onmuş, O., Şekercioglu, Ç. H., and Bilgin, R. (2013). Using Citizen Science Data to Model the Distributions of Common Songbirds of Turkey Under Different Global Climatic Change Scenarios. *PLoS ONE* 8 (7), e68037. doi:10.1371/journal.pone.0068037
- Adler, F. R., Green, A. M., and Şekercioglu, Ç. H. (2020). Citizen Science in Ecology: a Place for Humans in Nature. *Ann. N.Y. Acad. Sc.* 1469 (Issue 1), 52–64. doi:10.1111/nyas.14340
- Amano, T., Lammung, J. D. L., and Sutherland, W. J. (2016). Spatial Gaps in Global Biodiversity Information and the Role of Citizen Science. *BioScience* 66 (5), 393–400. doi:10.1093/biosci/biw022
- Anufriev, G. A. (1970). New Genera of Palaearctic Dikraneurini (Homoptera, Cicadellidae, Typhlocybinae). *Bull. de l'Academie Polonaise des Sci. (Serie des Sci. Biologiques)* 18 (5), 261–263.
- Aristeidou, M., Herodotou, C., Ballard, H. L., Young, A. N., Miller, A. E., Higgins, L., et al. (2021). Exploring the Participation of Young Citizen Scientists in Scientific Research: The Case of iNaturalist. *PLoS ONE* 16, e0245682. doi:10.1371/journal.pone.0245682
- Ball, E. D. (1933). The Genus *Myndus* Stål in North America (Homoptera: Fulgoridae). *J. Wash. Acad. Sci.* 23 (10), 478–484.
- Barrantes, E. A., Echavarría, M. A. Z., Bartlett, C. R., Helmick, E. E., Cummins, P., Ascunce, M. S., et al. (2020). A New Species of Planthopper in the Genus *Anotia* Kirby (Hemiptera: Auchenorrhyncha: Derbidae) from Coconut palm in Costa Rica. *Zootaxa* 4763 (1), 50–60. doi:10.11646/zootaxa.4763.1.4
- Boersch-Supan, P. H., Trask, A. E., and Baillie, S. R. (2019). Robustness of Simple Avian Population Trend Models for Semi-Structured Citizen Science Data is Species-dependent. *Biol. Conservation* 240, 108286. doi:10.1016/j.biocon.2019.108286
- Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., et al. (2014). Next Steps for Citizen Science. *Science* 343 (6178), 1436–1437. doi:10.1126/science.1251554
- BugGuide (2021). Iowa State University. Available at: <https://bugguide.net/node/view/15740>. (Accessed May 11, 2021)
- Caldwell, J. S. (1949). A Generic Revision of the Treehoppers of the Tribe Ceresini in America north of Mexico, Based on a Study of the Male Genitalia. *Proc. United States Natl. Mus.* 98, 491–521. doi:10.5479/si.00963801.98-3234.491
- Caldwell, J. S., and Martorell, L. F. (1952). Review of the Auchenorrhynchos Homoptera of Puerto Rico Part I Cicadellidae. *Jaupr* 34 (1), 1–32. doi:10.46429/jaupr.v34i1.12836
- Carlson, J. C., Fox, M. S., and McClarin, J. (2012). Passive Surveillance in Medical Entomology Using BugGuide. *Am. Entomologist* 58 (1), 29–31. doi:10.1093/ae/58.1.0029
- Chandler, D. S., and Hamilton, K. G. A. (2017). Biodiversity and Ecology of the Leafhoppers (Hemiptera: Cicadellidae) of New Hampshire. *Trans. Am. Entomol. Soc* 143 (4), 773–971. doi:10.3157/061.143.0408
- Chandler, M., See, L., Copas, K., Bonde, A. M. Z., López, B. C., Danielsen, F., et al. (2017). Contribution of Citizen Science Towards International Biodiversity Monitoring. *Biol. Conservation* 213, 280–294. doi:10.1016/j.biocon.2016.09.004
- Ciafré, C., and Barringer, L. E. (2017). First Record of the Ligurian Leafhopper, *Eupteryx decemnotata* Rey (Hemiptera: Cicadellidae) in Pennsylvania. *Insecta Mundi*, 0576
- Clark, C. J. (2017). eBird Records Show Substantial Growth of the Allen's Hummingbird (*Selasphorus Sasin Sedentarius*) Population in Urban Southern California. *The Condor* 119 (1), 122–130. doi:10.1650/CONDOR-16-153.1
- Cooper, C. (2016). *Citizen Science: How Ordinary People Are Changing the Face of Discovery*. New York: Abrams. doi:10.1093/obo/9780199743292-0180
- Cox, J., Oh, E. Y., Simmons, B., Lintott, C., Masters, K., Greenhill, A., et al. (2015). Defining and Measuring Success in Online Citizen Science: A Case Study of Zooniverse Projects. *Comput. Sci. Eng* 17 (4), 28–41. doi:10.1109/MCSE.2015.65
- Deitz, L. L. (2008). Cicadas. DrMetcalf: A Resource on Cicadas, Leafhoppers, Planthoppers, Spittlebugs, and Treehoppers. Available at: <https://www.lib.ncsu.edu/specialcollections/digital/metcalf/index.html>. (Accessed May 11, 2021)
- Deitz, L. L., and Wallace, M. S. (2012). Richness of the Nearctic Treehopper Fauna (Hemiptera: Aetalionidae and Membracidae). *Zootaxa* 3423, 1–26. doi:10.11646/zootaxa.3423.1.1
- Dietrich, C. (2013). "Overview of the Phylogeny, Taxonomy and Diversity of the Leafhopper (Hemiptera: Auchenorrhyncha: Cicadomorpha: Membracoidea: Cicadellidae) Vectors of Plant Pathogens," in Proceedings of the 2013 International Symposium on Insect Vectors and Insect-Borne Diseases, 47–70.
- Dietrich, C. H., and Dmitriev, D. A. (2007). Revision of the New World Leafhopper Genus *Neozygina* Dietrich & Dmitriev (Hemiptera: Cicadellidae: Typhlocybinae: Erythroneurini). *Zootaxa* 1475, 27–42.

- Fabricius, J. C. (1775). Rhyngota. Systema Entomologiae: Sistens Insectorum Classes, Ordines, Genera, Species, Adiectis Synonymis, Locis, Descriptionibus, Observationibus. *Officina Libraria Kortii. Flensburgi et Lipsiae*, 1–816.
- Fabricius, J. C. (1781). Ryngota. Species insectorum: exhibentes eorum differentias specificas, synonyma auctorum, loca natalia, metamorphosin, adiectis observationibus, descriptionibus. Impensis C. E. Bohnii. *Hamburgi et Kilonii* 2, 1–517.
- Fink, D., Auer, T., Johnston, A., Ruiz-Gutierrez, V., Hochachka, W. M., and Kelling, S. (2020). Modeling Avian Full Annual Cycle Distribution and Population Trends with Citizen Science Data. *Ecol. Appl.* 30 (3), e02056. doi:10.1002/eap.2056
- Fournier, A. M. V., Sullivan, A. R., Bump, J. K., Perkins, M., Shieldcastle, M. C., and King, S. L. (2017). Combining Citizen Science Species Distribution Models and Stable Isotopes Reveals Migratory Connectivity in the Secretive Virginia Rail. *J. Appl. Ecol.* 54 (2), 618–627. doi:10.1111/1365-2664.12723
- Goula, M., Sesma, J. M., and Vivas, L. (2013). Photosharing Websites May Improve Hemiptera Biodiversity Knowledge and Conservation. *ZooKeys* 319, 93–105. doi:10.3897/zookeys.319.4342
- Gubin, A. I., Martynov, V. V., and Nikulina, T. V. (2020). *Tautoneura polymytusa* Oh & Jung, 2016 (Hemiptera: Auchenorrhyncha: Cicadellidae): A New Alien Leafhopper Species in the Fauna of Eastern Europe. *Russ. J. Biol. Invasions*. 11 (4), 310–313. doi:10.1134/S2075111720040037
- Halbert, S. E. (2009). TRI-OLOGY. Available at: https://www.fdacs.gov/content/download/12560/file/triology_4803.pdf. (Accessed May 11, 2021). doi:10.3983/twc.2009.0041
- Hamilton, K. G. A. (1983). Introduced and Native Leafhoppers Common to the old and new Worlds (Rhynchota: Homoptera: Cicadellidae). *Can. Entomol.* 115, 473–511. doi:10.4039/ent115473-5
- Hamilton, K. G. A. (2011). What We Have Learned from Shutterbugs. *Am. Entomologist*. 57 (2), 102–109. doi:10.1093/ae/57.2.102
- Hamilton, K. G. A. (2012). Are Treehoppers Neotenus Leafhoppers? *Am. Entomologist*. 58 (4), 224–232. doi:10.1093/ae/58.4.224
- Hamilton, K. G. A. (2015). A New Tribe and Species of Clastopterinae (Hemiptera: Cercopoidea: Clastopteridae) From Africa, Asia and North America. *Zootaxa*. 3946 (2), 151–189. doi:10.11646/zootaxa.3946.2.1
- Hamilton, K. G. A., and Langor, D. W. (1987). Leafhopper Fauna of Newfoundland and Cape Breton Islands (Rhynchota: Homoptera: Cicadellidae). *Can. Entomol.* 119 (7–8), 663–695. doi:10.4039/ENT119663-7
- Hand, E. (2010). Citizen Science: People Power *Nature*, 466 (7307), 685–687. doi:10.1038/466685a
- Holzinger, W. E., Huber, E., Schlosser, L., and Kunz, G. (2020). *Acanalonia conica* (Say, 1830) and Three Other True Hopper Species New for Austria (Hemiptera: Auchenorrhyncha). *Cicadina*. 19, 9–19. Available at: <https://www.inaturalist.org/>.
- Horns, J. J., Adler, F. R., and Şekercioğlu, Ç. H. (2018). Using Opportunistic Citizen Science Data to Estimate Avian Population Trends. *Biol. Conservation*. 221, 151–159. doi:10.1016/j.biocon.2018.02.027
- Horton, K. G., Van Doren, B. M., La Sorte, F. A., Fink, D., Sheldon, D., Farnsworth, A., et al. (2018). Navigating North: How Body Mass and Winds Shape Avian Flight Behaviours across a North American Migratory Flyway. *Ecol. Lett.* 21 (7), 1055–1064. doi:10.1111/ele.12971
- Horváth, G. (1921). Description d'un Fulgoride nouveau des dattiers. *Bull. de la Société d'Histoire Naturelle de l'Afrique du Nord* 12, 179–180.
- iDigBio (2021). Available at: <https://www.idigbio.org/portal/search>. (Accessed May 11, 2021)
- Jarvis, R. M., Bollard Breen, B., Krägeloh, C. U., and Billington, D. R. (2015). Citizen Science and the Power of Public Participation in marine Spatial Planning. *Mar. Pol.* 57, 21–26. doi:10.1016/j.marpol.2015.03.011
- Johnson, D. M. (1935). Leafhoppers of Ohio. Subfamily Typhlocybinae (Homoptera: Cicadellidae). *Bull. Ohio Biol. Surv.* 31, 39–122.
- Kirby, W. (1821). II. The Characters of *Otiocerus* and *Anotia*, Two New Genera of Hemipterous Insects Belonging to the Family of Cicadidae: with a Description of Several Species. *Trans. Linn. Soc. Lond. (Second series) Zoolog.* 13, 12–23. doi:10.1111/j.1095-8339.1821.tb00049.x
- Kittelberger, K., and Howard, T. (2021). *Hoppers of North Carolina: Spittlebugs, Leafhoppers, Treehoppers, and Planthoppers [Internet]*. Raleigh (NC): North Carolina Biodiversity Project and North Carolina State Parks. Available at <https://auth1.dpr.ncparks.gov/bugs/index.php>. (Accessed May 11, 2021)
- Kosovac, A., Ščiban, M., Pančić, I., Tóth, M., Ronkay, L., and Orosz, A. (2020). Revealing the Presence of the East Asian Leafhopper *Tautoneura polymytusa* (Hemiptera: Auchenorrhyncha: Cicadellidae: Typhlocybinae) in Serbia Through Dna Barcoding. *Acta Entomologica Serbica* 25 (1), 83–86. doi:10.5281/ZENODO.3878684
- Lallemand, V. (1939). Cercopides nouveaux de Musée National Hongrois (Budapest). *Ann. Historico-Naturales Musei Nationalis Hungarici. Budapest* 32, 58–64.
- Leavengood, J. M., Bartlett, C. R., and Vitanza-Hedman, S. (2017). First Reports of Six Planthoppers (Hemiptera: Fulgoroidea: Tagosodes, Delphacodes, Pareuidella, Nilaparvata, Asarcopus, Bruchomorpha) in Texas. *Entomol. News* 127 (3), 215–229. doi:10.3157/021.127.0305
- Lees, A. C., Devenish, C., Areta, J. I., de Araujo, C. B., Keller, C., Phalan, B., et al. (2021). Assessing the Extinction Probability of the Purple-Winged Ground Dove, an Enigmatic Bamboo Specialist. *Front. Ecol. Evol.* 9, 1–14. doi:10.3389/fevo.2021.624959
- LeGrand, H., and Howard, T. (2021). *Butterflies of North Carolina: Their Distribution and Abundance. 28th Approximation [Internet]*. Raleigh (NC): North Carolina Biodiversity Project and North Carolina State Parks. Available at <https://auth1.dpr.ncparks.gov/nbnc/a/accounts.php>. (Accessed May 11, 2021)
- LeGrand, H., Howard, T., Petranka, J., and Shields, M. (2021). *The Dragonflies and Damselflies of North Carolina. 12th Approximation [Internet]*. Raleigh (NC): North Carolina Biodiversity Project and North Carolina State Parks. Available at <https://auth1.dpr.ncparks.gov/odes/a/accounts.php>. (Accessed May 11, 2021)
- Linnaeus, C. (1761). II. Hemiptera. Cicada. Fauna Svecica: Sistens Animalia Sveciae Regni: Mammalia, Aves, Amphibia, Pisces, Insecta, Vermes, Distributa Per Classes & Ordines, Genera & Species, Cum Differentiis Specierum, Synonymis Auctorum. Editors L. Salvii and Stockholmiae 578, 1–2.
- Matsumura, S. (1932). Homoptera Dainippon Gaichu Zusetu. = [Conspectus of Japanese Injurious insects]. Tokyo: Meiji Tosho, Showa 7 nen 1-971, 1–116.
- Matsumura, S. (1910). Neue Cicadinen aus Europa und Mittelmeergebiet (Schluss). *J. Coll. Sci. Imperial Univ. Tokyo* 27 (18), 1–38.
- McKamey, S. H., and Sullivan-Beckers, L. (2019). First Record of the Treehopper Tribe Darnini (Hemiptera: Membracidae: Darninae) From Eastern United States Based on Specimens of a new Species Excavated from *Hoplosoides* Wasp Nests. *Proc. Entomol. Soc. Wash* 121 (3), 449–460. doi:10.4289/0013-8797.121.3.449
- Melichar, L. (1903). *Homopteren-Fauna von Ceylon*. Berlin: Verlag von Felix L. Dames. i-iv, 1–248.
- Montgomery, G. A., Dunn, R. R., Fox, R., Jongejans, E., Leather, S. R., Saunders, M. E., et al. (2020). Is the Insect Apocalypse upon Us? How to Find Out. *Biol. Conservation* 241, 108327. doi:10.1016/j.biocon.2019.108327
- NCBP (2017). North Carolina Biodiversity Project. Available at: <https://nc-biodiversity.com/> (Accessed May 11, 2021).
- Neate-Clegg, M. H. C., Horns, J. J., Adler, F. R., Kemahlı Aytekin, M. Ç., Şekercioğlu, Ç. H., and Şekercioğlu, Ç. H. (2020). Monitoring the World's Bird Populations With Community Science Data. *Biol. Conservation* 248, 108653. doi:10.1016/j.biocon.2020.108653
- Newman, E. (1853). *Typhlocyba filicum*. *Trans. Entomol. Soc. Lond. (Ser. 2)* 2, 132–133.
- Nickel, H., and Remane, R. (2002). Artenliste der Zikaden Deutschlands, mit Angabe von Nährpflanzen, Nahrungsbreite, Lebenszyklus, Areal und Gefährdung (Hemiptera, Fulgoromorpha et Cicadomorpha). *Beiträge zur Zikadenkunde* 5, 27–64.
- Pélozuelo, L., Bourgoin, T., and Reynaud, P. (2020). A New Alien Species in France: First Records of the green Cone-Headed Planthopper *Acanalonia conica* (Say, 1830) (Hemiptera, Fulgoromorpha, Acanaloniidae). *Bull. Soc. Entomol. Fr* 125 (4), 423–426. doi:10.32475/bsef_2172
- Plummer, C. C. (1936). New Membracidae (Homoptera) from Mexico, with Notes on Other Species. *Ann. Entomol. Soc. America* 29 (4), 682–693. doi:10.1093/aesa/29.4.682
- Rey, C. (1891). Observations sur quelques Hémiptères-Homoptères et descriptions d'espèces nouvelles ou peu connues. *Revue D'entomologie. Publiée Par La Société Française D'entomologie* 10, 240–256.

- Robinson, O. J., Ruiz-Gutierrez, V., Fink, D., Meese, R. J., Holyoak, M., and Cooch, E. G. (2018). Using Citizen Science Data in Integrated Population Models to Inform Conservation. *Biol. Conservation* 227, 361–368. doi:10.1016/j.biocon.2018.10.002
- Sahlberg, J. R. (1871). Öfversigt af Finlands och den Skandinaviska hälftens Cicadariae. I. Notiser ur Sällskapets pro Fauna et Flora. *Fennica Förhandlingar* 9 (12), 1–506.
- Say, T. (1830). Descriptions of New North American Hemipterous Insects Belonging to the First Family of the Section Homoptera of Latreille. (Continued). *J. Acad. Nat. Sci. Philadelphia* 6, 299–314.
- Seltzer, C. (2019). Making Biodiversity Data Social, Shareable, and Scalable: Reflections on iNaturalist & Citizen Science. *Biss* 3. doi:10.3897/biss.3.46670
- Sullivan, B. L., Phillips, T., Dayer, A. A., Wood, C. L., Farnsworth, A., Iliff, M. J., et al. (2017). Using Open Access Observational Data for Conservation Action: A Case Study for Birds. *Biol. Conservation* 208, 5–14. doi:10.1016/j.biocon.2016.04.031
- Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., and Kelling, S. (2009). eBird: A Citizen-Based Bird Observation Network in the Biological Sciences. *Biol. Conservation* 142 (10), 2282–2292. doi:10.1016/j.biocon.2009.05.006
- Takiya, D. M. (2007). *Systematic Studies on the Leafhopper Subfamily Cicadellinae (Hemiptera: Cicadellidae)*. [University of Illinois at Urbana-Champaign]. Available at: <https://www.ideals.illinois.edu/handle/2142/86461>. (Accessed May 11, 2021)
- Tasi, A., and Lucky, A. (2020). Ligurian Leafhopper *Eupteryx decemnotata* (Rey) (Insecta: Hemiptera: Cicadellidae: Typhlocybinae). University of Florida: IFAS Extension. doi:10.32473/edis-in1290-2020
- Theobald, E. J., Ettinger, A. K., Burgess, H. K., DeBey, L. B., Schmidt, N. R., Froehlich, H. E., et al. (2015). Global Change and Local Solutions: Tapping the Unrealized Potential of Citizen Science for Biodiversity Research. *Biol. Conservation* 181, 236–244. doi:10.1016/j.biocon.2014.10.021
- Tóth, M., Orosz, A., and Rédei, D. (2017). Another Alien on the Horizon? First European Record of *Tautoneura polymitusa*, an East Asian Leafhopper (Hemiptera: Auchenorrhyncha: Cicadellidae). *Zootaxa* 4311 (1), 137. doi:10.11646/zootaxa.4311.1.10
- Uhler, P. R. (1876). List of Hemiptera of the Region West of the Mississippi River, Including Those Collected during the Hayden Explorations of 1873. *Bull. United States Geol. Geographical Surv. Territories* 1 (5), 269–361.
- Uhler, P. R. (1896). Summary of the Hemiptera of Japan presented to the United States National Museum by Professor Mitzukuri. *Proceedings of the United States National Museum*. Washington. 19: 255–297.
- Van Duzee, E. P. (1915). The North American Species of *Draeculacephala* (Homoptera). *Entomol. News* 26 (4), 176–181.
- Wagner, D. L., Grames, E. M., Forister, M. L., Berenbaum, M. R., and Stopak, D. (2021). Insect Decline in the Anthropocene: Death by a Thousand Cuts. *Proc. Natl. Acad. Sci. USA* 118 (Issue 2), e2023989118. doi:10.1073/PNAS.2023989118
- Walker, F. (1851). *List of the Specimens of Homopterous Insects in the Collection of the British Museum*, London: British Museum (4), 637–907.
- Walker, J., and Taylor, P. D. (2017). Using eBird Data to Model Population Change of Migratory Bird Species. *Ace* 12 (1). doi:10.5751/ACE-00960-120104
- Wallace, M. S. (2018). A New Species of Telamonini From the Eastern United States and the Taxonomic Limits of *Telamona salvini* Distant (Hemiptera: Membracidae: Smiliinae). *Proc. Entomol. Soc. Wash* 120 (3), 605–615. doi:10.4289/0013-8797.120.3.605
- Wheeler, A. G., and Wilson, S. W. (2014). The Cixiid Planthopper *Haplaxius ovatus* (Ball) (Hemiptera: Fulgoroidea): Association with Switchgrass (*Panicum virgatum*; Poaceae) and New Distribution Records. *Proc. Entomol. Soc. Wash* 116 (3), 358–368. doi:10.4289/0013-8797.116.3.358
- Wilson, J. S., Pan, A. D., General, D. E. M., and Koch, J. B. (2020). More Eyes on the Prize: an Observation of a Very Rare, Threatened Species of Philippine Bumble Bee, *Bombus irisensis*, on iNaturalist and the Importance of Citizen Science in Conservation Biology. *J. Insect Conserv* 24 (4), 727–729. doi:10.1007/s10841-020-00233-3
- Xu, Y., Dietrich, C. H., Zhang, Y. L., Dmitriev, D. A., Zhang, L., Wang, Y. M., et al. (2021). Phylogeny of the Tribe Empoascini (Hemiptera: Cicadellidae: Typhlocybinae) Based on Morphological Characteristics, With Reclassification of the *Empoasca* Generic Group. *Syst. Entomol* 46 (1), 266–286. doi:10.1111/syen.12461
- Zahniser, J. N., Taylor, S. J., and Krejca, J. K. (2010). First Reports of the Invasive Grass-Feeding Leafhopper *Balclutha rubrostriata* (Melichar) (Hemiptera: Cicadellidae) in the United States. *Entomol. News* 121 (2), 132–138. doi:10.3157/021.121.0204

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2021 Kittelberger, Hendrix and Şekercioglu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.