THESIS

# EXPERTS VS. NOVICES: A COMPARISON OF THE QUALITY AND QUANTITY OF *BOMBUS* OBSERVATIONS BETWEEN CITIZEN SCIENTISTS AND RESEARCHERS IN NATIONAL PARKS

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# ABSTRACT

EXPERT VS. NOVICES: A COMPARISON OF THE QUALITY AND QUANTITY OF *BOMBUS* OBSERVATIONS BETWEEN CITIZEN SCIENTISTS AND RESEARCHERS IN NATIONAL PARKS

Citizen science data is plentiful and diverse in its collection, storage, and subsequent application. Different platforms have unique methods of storing data and limitations in accessing the data contributed to the platform. This study explored the accessibility of citizen science data from several citizen science platforms and compared two different methods of collecting data from iNaturalist, a global citizen science platform for observing and identifying organisms. It focused on *Bombus* species observations made in Grand Teton and Yellowstone National Parks. The study found that different platforms are not equal in the ability to access and utilize data. It also found that on iNaturalist one method of searching for data yielded 14% more results than the other. The separate and incomplete nature of accessible data across citizen science platforms and subjectivity of searching methods on iNaturalist are indicative of the difficulty in creating a complete dataset that is representative of the collective contributions of citizen scientists.

The validity of citizen science research has been controversial in recent history. There is a general consensus, however, that citizen science must be verifiable to be trustworthy. iNaturalist is a crowdsourced citizen science platform that allows other users to corroborate or dispute species identifications that individuals post. This research seeks to determine whether there is a difference in the quantity and quality of *Bombus* observations in Grand Teton and Yellowstone National Parks made by expert researchers and citizen scientists on iNaturalist. It

found that the professional researchers, or experts, contributed 68% of the observations, but there was not a significant difference between the achievement rate of Research Grade observations between the experts and novices. This indicates that citizen scientists have the ability, through iNaturalist, to accurately make difficult taxonomic identifications.

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## Introduction

### The Significance of *Bombus*

Pollinators are an integral part of a variety of ecosystems and crop production, and pollinator decline is a major concern worldwide (Vasiliev et al., 2020). Since 2006, beekeepers have reported a nearly 30% decrease in colony population ("Disappearing Pollinators"). Of additional concern is the lack of statistics on the rate of wild and native pollinator decline and distribution patterns. Part of the reason for this may be that pollinator research is highly labor intensive, and it requires 'boots on the ground' to assess abundance and diversity patterns of pollinators within large areas. Because of the intensity and cost of implementation, pollinator research outside maintained hives and croplands is highly lacking, despite the widely understood importance of pollinators.

### Citizen Science

Citizen science involves the participation of members of the public, specifically nonscientists, in scientific research, usually in collaboration with professional scientists (Oxford, 2014). It is one method through which research can be conducted and is a way to achieve higher rates of data collection across greater spatial and temporal scales. It also has widespread uses in education, outreach, and public engagement. People are typically connected to a citizen science project through one of many web-based citizen science platforms like CitSci.org, Zooniverse, Merlin Bird ID, iNaturalist, or BeeWatch. In citizen science projects, participants volunteer to conduct some aspect of research. It can be done remotely (looking at databases or running online programs), or in person, and participants can be involved at varying participation levels, durations, and project types. People can identify images from home, volunteer in a lab setting to identify and sort samples, or work in the field collecting data themselves.

Citizen science can be broken down into 3 broad categories of participation: *contributory* (participants collect data and can help in analysis and dissemination of data); *collaborative* (participants analyze data and can help with designing the study and interpreting data); and *co-created* (participants help in all stages from developing questions and hypotheses, collecting data and analyzing results) (Follett et al., 2015). Crowdsourced iNaturalist observations fall into the 'contributory' category. It involves hands-on, in-person collection and identification of images or specimens in the field. The data is subsequently available on iNaturalist for scientists to use and analyze based on their research questions. It also contributes to an overall database that may be used to track and assess abundance and diversity patterns.

Citizen Science Applications

Citizen Science can contribute significantly to spatio-temporal gaps that exist within datasets. Temporally, citizen science can create long-term datasets that would otherwise be incredibly intensive, and potentially difficult to fund for researchers to do alone. One study compared longhorn beetle abundance patterns observed by citizen scientists with models depicting their behavior. Citizen science data was found to accurately represent inter-annual fluctuations in longhorn beetle species spanning from 1930-2000 (Snäll, 2013). This study is significant in its findings because it was able to compare the citizen science data with an established and previously implemented model. The model represents a baseline for what should be observed and found citizen science data to be aligned.

A marine citizen science project in Indonesia tracked benthic cover of biotic and abiotic species between 2002-2012. It revealed a decline in hard coral abundance, supporting the ability of citizen science to detect long-term ecosystem changes, especially where funding for monitoring is not available (Gouraguine et al., 2019). This study resulted in the implementation of management decisions as a direct result of data collected by citizen scientists. Without that data, there may not have been sufficient evidence of the abundance changes observed to implement effective management. One study, focused on mapping the density of roads within a region, utilized citizen science to collect data over a large area, leading to management actions (Valerio et al., 2021). This highlights the ability of citizen science data to cover large spatial areas, and create maps of features.

Citizen science can also span spatio-temporal questions. One citizen science initiative, the Biological Records Center (BRC) is a project established in 1964 with the goal of recording freshwater fish in the United Kingdom. Since its inception in 1964, the more than 70,000 participants annually have shown national distributions of 12,127 species and quantified the trends of 1,636 species (Pocock et al., 2015). This one project is the collection of observations across large spans of space and time to create a cohesive database that comes closer to reflecting true population distributions and trends. A dataset of this nature is critical for understanding abundance and diversity patterns and subsequently observing when those patterns are shifting. These large-scale projects are not without challenges. One of the challenges noted within this project, which is seen across citizen science projects globally, is the need to verify and validate the observations that citizen scientists are making.

Citizen Science Accuracy and Validation

Citizen science results are generally thought, by researchers and stakeholders, to be less accurate and less reliable than data collected by scientists. Data accuracy can be defined as the degree of correctness of a given submission or collection of data (Redman, 2005), and for this study specifically refers to the degree to which species level identifications are correct.

The research on citizen science data accuracy is broad in its questions and methods of analysis. Some research projects focus on the accuracy of participant observations within a given citizen science project. For example, one project focused on *Bombus* observations found that observers were only correct in their identifications between 40-60% of the time, but that accuracy increased as an individual made more identifications (Falk et al., 2019). Some citizen science projects with a focus on data accuracy seek to assess data collected from crowdsourced citizen science platforms (Anderson, 2020; Beckham, 2017). Others assess different amounts of training to see what connections might exist between training and data accuracy, or evaluate different levels of training to compare data accuracy.

One study that was focused on the impact of different training methods and amounts on citizen science data accuracy found that a higher level of training resulted in an increase in identification accuracy, but that the observations made by citizen scientists tended to be less accurate than those made by professionals (Ratnieks et al., 2016). Another study assessing the accuracy of plant identification among citizen scientists following standardized research protocols found that participants had high levels of accuracy (Fuccillio et al., 2014). It also found that people who had fewer observations had a comparable error rate to those who submitted far more observations. This indicated that a standardized protocol was enough to ensure high rates of accurate observations sufficient for research.

Research has indicated that citizen science must produce accurate data to be widely accepted and used by stakeholders across academia and industries (Follett et al., 2015). The study focused on coral reefs in Indonesia found that protocols that adhere to "sound scientific standards" are necessary in order to use citizen science to influence stakeholders and make management decisions (Gouraguine et al., 2019). Despite the evidence that more training can result in higher data accuracy, this might not always be an option. Intensive training requires time, money and resources that might not always be available, and, as a result, crowdsourced databases often contain huge quantities of observations. One citizen science platform, iNaturalist, contains more than 117,000,000 observations, with observations from more than 95% of countries represented. As a result of the widespread use of these platforms and the sheer quantity of data that exists within them, there is a need to assess the data collected by participants on these crowdsource platforms.

Citizen Science Data Management

The management of citizen science data varies drastically across platforms, and there is not a repository of data that spans platforms and projects. Additionally, within a platform, there may be numerous projects, across which you cannot search. For example, Project Noah utilizes projects that people can contribute to, but observations are not searchable across projects.

Having both separate platforms and separate projects within platforms can lead to overlapping data that remains separate. There might be one project focused on a species in one location, and another focused on the same species in a different location. Despite similarities in datasets across platforms, and sometimes projects, they often do not crossover. For example, there may be projects focused on streams in the Midwestern US organized separately on two different citizen science platforms. This results in the possibility that neither project is a fully accurate representation of the data that exists on the subject.

Because of the separation of platforms, there exist numerous patchy datasets as opposed to a few cohesive and useful ones (Bonney et al., 2014). Furthermore, there are concerns about platforms that do not allow data to be accessed by the public once it has been collected. Some argue that data collected by citizen scientists should be ‘open data’. The Open Knowledge Foundation defines open data as that which “can be freely used, modified, and shared by anyone for any purpose”. It is widely accessible at little to, preferably, no cost and is complete in its inclusion of data from across platforms. The concept of open data supports the democratization of science, and furthers the research that can be accomplished with citizen science (Vattakaven et al., 2022).

Obtaining Citizen Science Data

With the increasing number of citizen science platforms and more data continuously being collected, one might imagine that there is a swath of accessible data that researchers have at their disposal. Much of the data, however, is not easily retrievable. For example, on Bumblebee Watch observations can be searched for by province/state, county, species, project, year, month, observer, and verification status. This makes it difficult to collect data from a specific park like Yellowstone National Park which crosses state and county boundaries. Additionally, if researchers want to utilize the data it must be requested from Bumblebee Watch. The data can be viewed online without requesting it but cannot be downloaded.

Project Noah is a citizen science platform that also allows people to observe species and upload them from around the world. People can include the location of the observation and the date observed, along with defining characteristics of the organism. Others on the platform can then offer suggestions for species identifications. Similar to Bumblebee Watch, there are significant limitations to downloading data from the platform. There are ‘Missions’ on Project Noah that people can contribute to. Each one has a specific species or group of focus. Many are on a national or even global scale. Data can be downloaded from a Mission, including the Noah ID, Latitude, Longitude, Common Name, Scientific Name, Description, Habitat, Notes, Category, Continent, Country, Primary Image URL, Spotted Date, Submitted Date, Favorite Count, Suggestion Count, Comment Count, Tags, and Missions. A primary goal for Project Noah is education and the development of personal 'notebooks' including the observations a person has made. The focus of the platform does not seem to be on usability of the data for research projects outside the collection projects.

Zooniverse, one of the most widely used citizen science platforms, also lacks the ability to download data across projects if you are outside the project. It allows project creators to retain and download their own data, and some projects on Zooniverse contain publicly available data, but it is not all made publicly available for use by individual users outside the project.

A literature review centered around biomedical citizen science research found three characteristics that significantly influenced the data management practices of a citizen science project: the aims and objectives of the research; roles and functions of participants; the specific research platforms and tools used within the project (Borda et al., 2020). Although the focus of this research is not biomedical, there seems to be an overlap in the influence of these characteristics across citizen science projects within different fields.

<u>iNaturalist</u>

iNaturalist, a joint initiative created by the California Academy of Science and the National Geographic Society, is a platform and app that allows people to collect and upload species observations. There are currently more than 3.2 million users on the platform, and as of March 2023 more than 127 million observations have been made across the world. Any individual with access to a smartphone can post an image of an organism and make a taxonomic identification. They also have the ability to leave it unidentified. Individuals on the platform are able to support identifications or offer different species or genus identification.

Platforms like iNaturalist contain all of the uploads in one searchable dataset. Observations may be contributed to projects, but still populate in the overall platform observations. Because data can be pulled from across projects on the platform, it is easier to access everything that has been observed and uploaded to the platform.

Uploads that have a date and location, contain an image or sound, and are of an organism not captured or cultivated are considered to be 'Verifiable Observations'. Observations that do not meet these requirements are considered 'Casual' and do not meet the criteria to be considered for 'Research Grade' (RG) status. Once uploaded, other people on the platform can corroborate their identification or offer a different species, genus, or family identification. When 2/3 of the identifications provided by users are in consensus, the observation is said to have achieved RG status. If an observation has not yet received RG status, or the status cannot be achieved because of the nature of the observation (ie. blurry or distant image) the observation will remain as 'Needs ID' (NID). There is not a distinction between the observations tagged as NID that have yet to be identified and those that do not have the potential to be identified as a result of the quality of the image or sound.

## Methods

The aim of this portion of research was to obtain all the *Bombus* observations on iNaturalist in Grand Teton and Yellowstone National Parks. There are two main methods for searching for observations within a specific location (Figure 1): one utilizing the location search feature, and one by manually drawing the boundary around which you want to search. Both of the data pull methods were attempted to ensure that all the data possible could be collected.

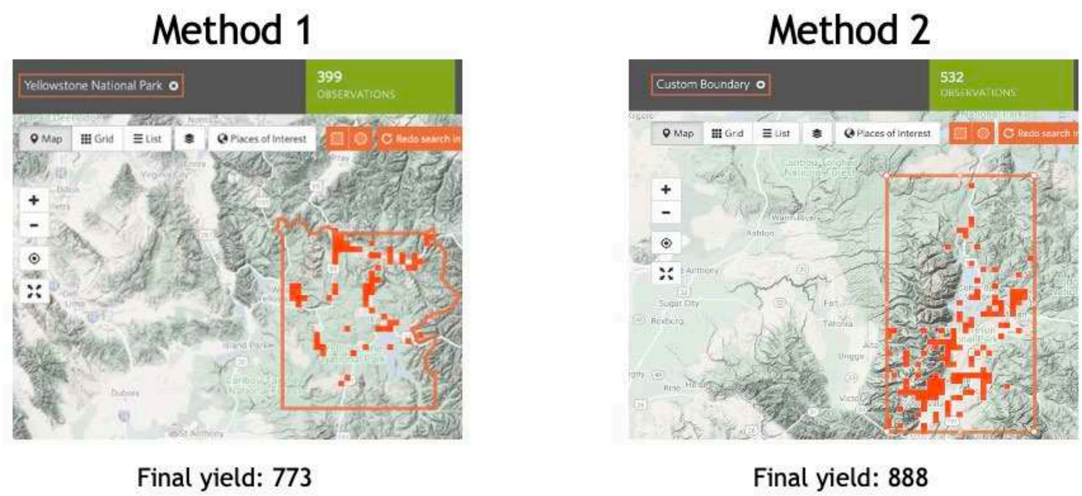


Figure 1: A sample of Method 1 and Method 2 data pull before observations outside the park have been manually removed.

Data Pull Method 1

Because of the accessibility of the database, the data used for this research was collected on iNaturalist. iNaturalist allows you to search for data with specific locations, species, or other factors. The data pull was intended to include all verifiable observations of organisms of the genus *Bombus* observed in Yellowstone National Park (YELL) or Grand Teton National Park (GRTE). "*Bombus" was* entered into the species search, and the name of the National Park into the 'Place' search function. This drew the bounds of the park map and populated results within the park.

Data Pull Method 2

A second method of searching for observations was utilized to ensure that the results gathered were a complete reflection of the observations on iNaturalist. This was done to ensure that all possible observations were recorded in the data pull. For the second data pull method I searched for "*Bombus"* using the same species search but drew the bounds manually around the park. iNaturalist allows you to draw a square or circular bound. Because of the shapes of the park, I drew a square around each park, ensuring that the entirety of the park was within the boundaries. I then manually removed the observations that were outside the park bounds using maps of the National Parks provided by the National Park Service (NPS).

I began by removing the observations that were visually evident as being outside the park using the Park map from the NPS website (NPS, 2023). The NPS website provides maps of both GRTE and YELL. These maps include a location search feature that allows for the input of geographic coordinates. For any observation that was on the border of the park boundary, I copied the observation coordinates provided by iNaturalist and pasted them into the location search for the park maps. The map indicates a square within which the coordinate lies, but does not give an exact location. Most observations were in a location in which the entire square was within park boundaries, indicating that they were definitely within the park. When a coordinate returned an image where part of the square was outside the park boundary it indicated that the observation was on the edge of the park boundary. For these observations I used Google Earth to identify specific locations based on roads and land features to determine whether the exact coordinate was inside or outside the bounds of the park. The observations that were considered outside the park boundaries were also confirmed using the latitudinal and longitudinal coordinates of the observation.

After removing all the observations outside the park boundaries, I isolated the observations that were geographically within the park boundaries but did not appear in the initial search using data pull method 1. I inputted these coordinates into the NPS maps to ensure that they were in fact located within the parks.

## Results

Number of Observations

The first search, using the location search feature on iNaturalist, yielded 392 results within YELL and 381 in GRTE, for a total of 773 results. The second search was conducted by manually drawing boundaries around the parks and removing results that were located outside the boundaries of the park. The final yield for this search was 419 in YELL and 469 in GRTE, equaling 888 total observations. This provided an additional 27 observations in YELL and 88 in GRTE, equaling an additional 115 observations overall. The second data pull method yielded 14% more results than the one using the location search feature.

What Was Missed

*GRTE*

There were 88 missed observations in the first search that the second search was able to detect within GRTE. 12 of the 88 missed observations had the coordinates obscured, which does not seem to indicate it being the reason they were missed because other observations with obscured coordinates were included in the first data pull. There were also differences in the "place_guess", which may have contributed to the discrepancy between what was included and excluded from the first data pull. One missed observation was the only observation titled "Grand Teton and Yellowstone National Parks, Wyoming, USA" There were 3 observations titled "Grand Teton National Park" that were excluded, but 5 that were included. There were also another 3 excluded titled "Grand Teton National Park, Alta, WY, US" and 5 by the same name that were included. There was one titled "Grand Teton National Park, Moose, WY, US", but 11 by the same name included. Another excluded observation that was the only one with its name was titled "Grand Teton NP - Wyoming, USA". All 6 observations titled "Jackson Lake, Alta, WY, US" were excluded, along with both of the observations titled "Jackson Lake, Jackson, WY, US". The single observations "North Bar Bay, Alta, WY, US" and "Spalding Bay, Jackson, WY, US" were also excluded. 3 of the 7 observations titled "Teton County, US-WY, US" from within the park were excluded, and an additional 7 observations with the same title were removed because they were outside the park. 9 of the 12 observations with the location "United States" were excluded and one was outside the park boundaries. 23 observations tagged as " Grand Teton National Park, Jackson, WY, US" were excluded. Finally, all 29 observations titled "Wyoming, USA" were excluded.

*YELL*

There were 27 observations that the first data pull missed that were included in the second data pull. Of the 233 observations with the "place_guess" tagged as "Park County, WY, USA" 1 was excluded from the first data pull. There were 6 observations with the location "Teton County, WY, USA", 3 of which were excluded. 8 out of the 10 place locations tagged as "United States" were excluded from the search. 3 of the 13 places tagged as "Yellowstone National Park" were excluded, along with 6 of the 10 tagged as "Yellowstone National Park, Alta, WY, US".

## Discussion

### Data Across Platforms

Across the citizen science platforms, there is a lack of standardization in data recording and the method of storing data. As a result, accessibility of data also varies greatly. Differing goals of citizen science projects contributed to the difficulty of pulling consistent data across platforms. Some platforms are not designed with the intent of the research being utilized past its collection. This is common with educational platforms.

These inconsistencies can lead to significant gaps in knowledge. If a species is observed on one platform but not another, the latter might not be an accurate reflection of the biodiversity of a location. Furthermore, there may be gaps in spatial effort that are not evident if there is no cohesive reporting of citizen science data. Patchy databases and inconsistent data pull results are indicative of an inability to guarantee that a citizen science dataset is complete and representative of the true data.

A wide scale database of citizen science platforms would significantly improve the cohesion and subsequent application of citizen science data. Alternatively, the push for citizen science data being 'open data' would prevent these problems from emerging.

Obtaining iNaturalist Data

The methods of pulling citizen science data, and subsequently the results yielded utilizing different methods, varied significantly. 14% of the final dataset was not recorded using the first method of data collection. This portion of data becomes important when dealing with a relatively small dataset. It may impact observations and conclusions about abundance and diversity patterns of the ecosystem.

It is unclear why some observations were recorded using the boundary search feature while others were not. They varied in location tag, coordinates, date posted, and RG status. It would be beneficial to know why some were excluded and others weren't with the same location. Another potential reason for inconsistent quantities of data between the two methods is changing park boundaries. Based on appearance between the boundaries populated by iNatualist in

Method 1 and the NPS Park Map the map on iNaturalist appears to be up to date. Changing park boundaries throughout the years may impact the data that is recorded as being presently in a given park. There may be implications for how data is uploaded, but more research would be required. iNaturalist offers the ability to download a more complete dataset than other platforms may allow, but it still has room to improve in the user's ability to download the complete dataset.

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Chapter 2

Experts vs. Novices: A Comparison Between Bombus Species Observations by Professional Researchers and Citizen Scientists on iNaturalist

## Introduction

### Citizen Science

The debate surrounding the validity and reliability of citizen science data is longstanding. One side of the debate argues that citizen scientists can collect reliable data, and highlights the amount of data that would not exist if researchers did not utilize citizen science data. The citizen science platform iNaturalist alone has greater than 140 million observations as of June 2023. The other side argues that people who are not trained and do not have experience doing science cannot conduct scientific research that can be trusted or validated. Both sides provide well-supported arguments. There is significantly more data available as a result of citizen scientist participation, but the validity of non-experts can be called into question.

Citizen science data is generally thought to be less accurate and less reliable than data collected by scientists (Ratnieks et al., 2016). Data reliability can take on several definitions. One definition of reliability, put forth by Oxford Dictionary is "the degree to which the result of a measurement, calculation, or specification can be depended on to be accurate". If data is reliable, it means that it is consistently accurate, and can be depended on to be accurate overall. Data accuracy can be defined as the degree of correctness of a given submission or collection of data (Redman, 2005), and for this study specifically refers to the degree to which species level identifications are supported by others on the platform.

This study focuses on *Bombus*, or bumble bee, observations posted to iNaturalist in Grand Teton and Yellowstone National Parks. It seeks to address two hypotheses. The first hypothesis is that the expert group collects more observations than the novice group because of their standardized effort and protocols when collecting data. The second hypothesis is that the expert group, having more experience and expertise with *Bombus* species, provides significantly more accurate data, meaning that their observations achieve Research Grade status more frequently than the novice group.

<u>*Bombus Species in Grand Teton and Yellowstone National Parks*</u>

The 250+ globally known *Bombus* species make up a diverse genus of bees that are part of the apidae family. They inhabit a wide range of habitats and can be found on all continents except Australia and Antarctica. There are 18 species of bumble bees that inhabit Grand Teton National Park (GRTE) and Yellowstone National Park (YELL). These species include *Bombus appositus, balteatus, bifarius, californicus, centralis, fervidus, flavifrons, frigidus, griseocollis, huntii, insularis, melanopygus, mixtus, nevadensis, occidentalis, rufocinctus, suckleyi, sylvicola*. As of April 2021, *Bombus fernaldae* was synonymized with *Bombus fervidus* (Lhomne et al., 2021), which is reflected on iNaturalist. The ranges of these species vary dramatically in size and overall geographic region, but all species found GRTE or YELL inhabit both parks. Because of the close proximity of the parks, they overlap completely in bumble bee species ranges.

<u>*Bee Citizen Science and* Data Validation</u>

One of the difficulties with citizen science is validating the research conducted by participants. The Data Management Body of Knowledge defines validity as “the degree to which data values are consistent within a defined domain”. This indicates that for data to be valid, it must be applicable and consistent within a given application. The validity of citizen science observations is widely debated, and seemingly project specific. Falk et al. (2019) found that of the observations contributed to Blooms for Bees, a citizen science project for observing bees, 72% (3,011) could be identified by scientists because they included clear images. This project was designed in a way that people could make observations to be identified at a later point by scientists, which is one way to account for issues regarding validation. Another study involving a cohesive literature review of iNaturalist assessments found that citizen science cannot be shown to be reliable unless participants have received training by professionals (Koo et al., 2022). One area in which citizen scientists fell short was in the accurate recording of location data. Koo et al. found that citizen scientists often misrecorded the location in which an observation was made because iNaturalist defaults to uploading from the location a person is in during the upload unless they specifically indicate that it was observed in a different location.

Within citizen science projects making pollinator identifications it is important that participants provide data that can be corroborated or disputed by scientists. The study by Falk did find, however, that tools like iNaturalist, that allow experts to analyze citizen science identifications, can increase overall accuracy within a project and make the data more reliable overall (2019). The identification made by the individual who uploaded it is not necessarily the final identification because it can be disputed or supported by other iNaturalist users.

## iNaturalist

iNaturalist is a citizen science platform that allows people from around the world to make and upload observations of organisms. It is very widely used and contains more than 140 million observations. Users are able to take a video or audio recording of an organism and upload it to the platform with an identification of the family, genus, or species. Others on the platforms are then able to support the identification or offer other suggestions. If an observation is Verifiable, meaning it includes a date, location, image, or sound, and a non-cultivated or captured organism, it has the ability to achieve Research Grade (RG) status. An observation is considered RG if ⅔ of the identifications made by others on the platform all suggest the same species identification. If a Verifiable Observation has not achieved RG status, whether it still requires identification or cannot be identified for any given reason, it Needs ID (NID).

## **iNaturalist Contributors**

### Citizen Scientists

In a 2019 paper, Parrish et al. break participation levels into three distinct categories: dabblers, steady volunteers and enthusiasts. Dabblers are people who make a small number of observations and do not have high retention. They do not make many observations individually and do not participate long-term, but they make up the majority (67-84%) of participants. Enthusiasts are people who consistently make observations and participate for a significant duration of time. They make most of the observations and have a high retention rate. Despite contributing most of the observations, they make up a very small portion of participants (1-4%). Steady volunteers fall somewhere in the middle in terms of retention and observation rate and represent 12-32% of the population. Although enthusiasts make up the majority of observations and have higher accuracy, Parrish et al. (2019) found that dabblers do provide useful data in that they are capable of making correct observations in addition to making up the bulk of participants.

The citizen science data is anything on iNaturalist that was not observed by the Pollinator Hotshots, a group of graduate students and interns from Colorado State University. Among the observers that contributed *Bombus* observations in YELL, the number of total observations an individual has made on iNaturalist ranges from 8 (user: h4h) to 105710 (user: fanatic; RIP). Although these are the extreme ends of the observation quantities, they are indicative of the wide range in which peoples' observation rates fall. Variation in the number of observations is reflective of the different levels at which people participate.

The majority of the users on iNaturalist would also fall into different categories depending on the statistic we measure. If we look at their contributions of specifically *Bombus* species in GRTE and YELL, most individuals would fall into the dabbler category. They contributed a few observations over the course of a day or few days. If we look at overall contributions, however, many of the observers would fall into the enthusiast category. These individuals contribute a high number of observations across years and across species. Although they have high levels of participation overall on iNaturalist, this does not indicate significant experience with, or frequent identification of, *Bombus* species. Because of the variability of the experience of the citizen scientists, they are broadly considered to be the novices. They may lack formal training or experience entirely with *Bombus* species before they make an observation.

Identifiers

The identifiers on iNaturalist are the people who suggest an ID for an observation that was uploaded by an observer. They can operate from anywhere in the world and suggest an ID for any verifiable upload. The identifiers on iNaturalist also vary in their participation levels. One user (johnascher) who identifies many *Bombus* observations in GRTE and YELL, a self-described Assistant Professor at National University of Singapore and Research Associate at Lee Kong Chian Natural History Museum and the American Museum of Natural History, has made more than 1.4 million identifications. This person, by all accounts, would be considered an expert. There are also identifiers who have made as few as 1 identification. A person with 1 identification might be considered a novice, indicating that among the identifiers there may also be novices and experts.

## Pollinator Hotshots

The Pollinator Hotshots (Hotshots) are a changing group of graduate students from Colorado State University (CSU) and hired interns. The graduate students are pursuing Master's or PhD's from CSU in either the Graduate Degree Program in Ecology (GDPE) or Ecosystem Science and Sustainability (ESS). Both groups work directly with Colorado State University researcher scientists in the field to conduct pollinator research in National Parks. The Hotshots have been sampling in Grand Teton National Park every summer since 2016. The Hotshots are trained in the field for at least one week before entering the parks for sampling and are educated in pollinator taxonomic identification. They work directly with researchers who are leading the crews making observations and identifications. Because of the training and direct supervision by researchers, the Pollinator Hotshots represent the experts. They are participating in funded research conducted by accredited research scientists and are following specific observation and recording methodology.

## Pollinator Hotshot Observation Methods

The Hotshots upload observations on iNaturalist, just like any other observer using the platform. The Hotshots, however, often share iNaturalist accounts in the field. The vast majority of observations made by this team were uploaded to the accounts 'swhippss, gwsn-peru, or rmssn'. Some individuals also used their personal accounts for uploading while in the field. Uploads on personal accounts during the field season in which the graduate student or intern was working have also been attributed to the Hotshots.

Prior to 2022, the Hotshots sampled specific field sites year to year using modified Pollard Walks. Pollard Walks were established as a standardized method of butterfly sampling that involves specific sample sites based on size, and a specific amount of time spent surveying that location (Pollard, 1977). The Hotshots utilized a sampling area of 100m in length. Along this route, researchers sample pollinators within 5 meters on either side of the centerline of the trail creating a sampling area of $500m^2$. In addition to pollinator observations, temperature (ºC), humidity (%), barometric pressure (mmhG), wind speed (m/s) and cloud cover (%) were also recorded at the beginning and end of each survey. This climate data was collected but not uploaded to iNaturalist as it is not within the bounds of what iNaturalist accepts or requires. This additional data was recorded in EpiCollect5, a data collecting application that can be used in the field without wifi and uploaded later. In 2022 the Hotshots continued to utilize Pollard Walks and collect climate data, but also standardized methods further. Pollard walks were still used to sample trails, but in meadows the crew used transects to make observations in specific areas. Random transects measuring either 100x40m or 200x20m were chosen within a meadow depending on the overall size of the area, and observations were made within the transects for 45 minutes. Additionally, the Hotshots also set a limit of 100 test tubes and collect until they were all filled. These methods were used in combination within different environments.

To collect pollinators during both the Pollard Walks and transect sampling, the Hotshots used butterfly nets. Bees were transferred to a test tube or petri dish and cooled in a lunchbox with ice for approximately 10 minutes. After the bee was cooled enough to remain still, it was removed from the ice and photographed. In accordance with the Hotshot protocols, most of the specimens were photographed on a solid white background. Some were photographed in a test tube when they were not able to be cooled. After being photographed with either a high resolution DSLR camera or a phone camera if the DSLR cameras were not available, the specimens were allowed to warm up and were released. Although providing an identification is optional on iNaturalist, the Hotshots uploaded identifications of all the specimens they recorded, and the observations were also recorded in EpiCollect5 at this time. Observations made in the field and recorded on EpiCollect5 were gathered and uploaded to iNaturalist periodically throughout the summer. iNaturalist allows you to record the observed date in addition to the date uploaded, making it easy to distinguish when the observation was actually made from when it was uploaded. Because the Hotshots recorded observations on EpiCollect5 while in the field, an accurate observation date and time were able to be uploaded to iNaturalist despite being uploaded at a later time.

## Methods

### Data Pull

The data pull sought to include all observations of organisms of the genus *Bombus* observed in Yellowstone (YELL) or Grand Teton National Parks (GRTE). "*Bombus*" was entered into the Species search, and the name of the National Park into the 'Place' search function. This drew the bounds of the park map and populated results within the park. This first search, using the location search feature on iNaturalist, yielded 392 results within YELL and 381 in GRTE, for a total of 773 results.

To confirm that this search method yielded all observations within the parks, the search for "*Bombus*" using the species search function was repeated. The bounds around GRTE and YELL were drawn manually. iNaturalist allows the user to draw a square or circular bound. Because of the shapes of the parks, a square was drawn around each park, ensuring that the entirety of the park was within the boundaries. All the observations within the manually drawn boundaries were then downloaded.

All the observations that were detected in the first data pull using only the park names and "*Bombus*" in the search functions were retained. The remainder of the observations needed to be manually sorted through to determine whether they were found inside or outside the park boundaries. These were sorted and manually removed using maps of the National Parks provided by the National Park Service (NPS) (NPS, 2023). The NPS website provides maps of both Grand Teton and Yellowstone National Parks. These maps include a location search feature that allows for the input of coordinates. For any observation that was on the border of the park boundary or was not found in the initial search using park names and "*Bombus*", the observation coordinates were copied from the iNaturalist, download, and pasted into the location search for the Park maps. The map indicates a square within which the coordinate lies but does not give an exact location. For most of the observations the entire square was either entirely inside or outside the park boundary and the location was confirmed. When a coordinate was on the edge of the park boundaries, Google Earth was used to identify specific locations based on roads and features of the land to determine whether the exact coordinate was within or without the bounds of the park.

The final yield for this search was 419 in YELL and 469 in GRTE, equaling 888 total observations. This provided an additional 27 observations in YELL and 88 in GRTE, equaling an additional 115 observations overall.

Data Analysis

The first step in the data analysis was to sort each park's observations into four groups: research grade observations made by the Hotshots (Hotshot RG), observations that need ID made by the hotshots (Hotshot NID), research grade observations made by citizen scientists (CitSci RG), and observations that need ID made by citizen scientists (CitSci NID). Once the data was sorted into these four categories, I was able to analyze the number of observations within each category, identify the species found in each park, and record which groups observed which taxonomic groups.

Once the data was sorted, I was able to determine the percentage of research grade observations made by the Hotshots and the citizen scientists for each species. Because the overall number of observations made by each group was so different, the percentages, as opposed to the number of research grade observations, standardized the comparison.

Following the data sorting and assessment of percentages, I conducted a Shapiro-Wilk test to determine if the datasets are normally distributed. It was found that the Hotshot % of research grade observations were not normally distributed, and the citizen scientist % of research grade observations were normally distributed. Because of the non-normal distribution of the Hotshot data, a Mann Whitney U test (Wilcoxon rank-sum) was used to test the hypothesis that the Hotshots contributed significantly more Research Grade observations than the citizen scientists because of their experience with and expertise in *Bombus* species.

## <u>**Results**</u>

### <u>Pollinator Hotshots Overall Observations</u>

#### *'Research Grade' Observations*

As of February 8th, the Hotshots made 122 'research grade' observations in YELL, and 103 RG observations in GRTE. This amounted to 225 RG observations between the two parks. These were observations for which the species identification was agreed upon by at least ⅔ of iNaturalist users. Among the 225 RG observations made by the Hotshots there were 13 species and 2 subspecies in GRTE. In YELL there were 1 genus, 1 subgenus, 1 subspecies and 15 species observed. The RG taxonomic observations made in GRTE included *Bombus appositus,* *bifarius, centralis, californicus, flavidus flavidus, flavifrons, griseocollis, huntii, insularis, melanopygus, nevadensis, occideentalis, rufocinctus, vancouverensis,* and *vancouverensis nearcticus.* The RG observations made by the Hotshots in YELL included *Bombus, Pyrobombus,* and species *Bombus appositus, bifarius, californicus, fervidus, flavifrons, griseocollis, huntii, insularis, melanopygus, mixtus, nevadensis, occidentalis, rufocinctus, sylvicola, vancouverensis* and *vancouverensis nearcticus.*

*'Needs ID' Observations*

In addition to the 225 RG observations, the Hotshots also contributed 194 observations that need ID in YELL, and 180 observations that need ID in GRTE. This provided an additional 375 observations made by the Hotshots in the two parks, resulting in a total of 600 made by the Hotshots between the two parks. The NID observations in YELL included 1 genus, 4 subgenera, 14 species, and 1 subspecies. These included *Bombus, Cullumanobombus, Psithyrus, purobombus, Thoracobombus, Bombus appositus, bifarius, californicus, centralis, fervidus, flavifrons, frigidus, huntii, insularis, mixtus, nevadensis, occidentalis, rufocinctus, sylvicola,* and *vancouverensis nearcticus.* In GRTE there were 1 genus, 2 subgenera, 14 species, and 1 subspecies observed. These included *Bombus, Psithyrus, Pyrobombus, Bombus appositus, bifarius, californicus, centralis, fervidus, flavidus, flavifrons, frigidus, huntii, insularis, melanopygus, nevadensis, rufocinctus, sylvicola,* and *flavidus flavidus.*

<u>Citizen Scientist Overall Observations</u>

*'Research Grade' Observations*

The research grade observations made by iNaturalist users totaled 91 between the two parks. There were 58 RG observations in GRTE and 33 in YELL. In GRTE there were 1 genus, 1 subgenus, 12 species and 2 subspecies observed. These included *Bombus, Pyrobombus, Bombus appositus, bifarius, centralis, fervidus, flavifrons, huntii, insularis, mixtus, nevadensis, occudentalis, rufocinctus, vancouverensis, flavidus flavidus,* and *vancouverensis nearcticus.* In YELL there were 1 genus, 1 subgenus, and 11 species. These groups included *Bombus, Pyrobombus, Bombus, appositus, bifarius, centralis, fervidus, flavifrons, huntii, insularis, melanopygus, nevadensis, occidentalis,* and *rufocinctus.*

*'Needs ID' Observations*

In GRTE there were 124 NID observations, and in YELL there were 68. This resulted in 192 NID observations between the two parks. In GRTE there were 1 genus, 3 subgenera, and 12 species observed. They included *Bombus, Psithyrus, Pyrobombus, Subterraneobombus, Bombus appositus, bifarius, centralis, fervidus, flavifrons, huntii, insularis, melanopygus, mixtus, occidentalis, sylvicola,* and *vancouverensis.* In YELL there were 1 genus, 2 subgenera, and 12 species, including *Bombus, Psithyrus, Pyrobombus, Bombus bifarius, californicus, centralis, fervidus, flavifrons, huntii, insularis, mixtus, nevadensis, occidentalis, rufocinctus,* and *vancouverensis.*

<u>Overall Species Observed by Group</u>

Between GRTE and YELL there were 26 taxonomic groups observed (Figures 2-4). These included 1 genus, 5 subgenera, 18 species, and 2 subspecies. Within the *Bombus* genus, the subgenera *Cullumanobombus* ,*Psithyrus, Pyrobombus, Subterraneobombus,* and *Thoracobombus* were observed. The species observed included *Bombus appositus, bifarius, californicus, centralis, fervidus, flavidus, flavifrons, frigidus, griseocollis, huntii, insularis,* *melanopygus, mixtus, nevadensis, occidentalis, rufocinctus, sylvicola,* and *vancouverensis.* The two subgenera observed were *Bombus flavidus flavidus* and *Bombus vancouverensis nearcticus.*

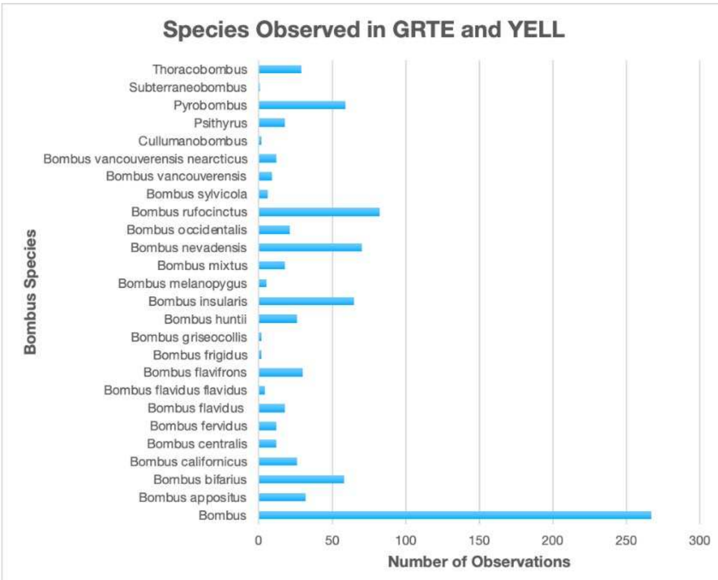


Figure 2: The quantity of each species observed in Grand Teton and Yellowstone National Parks

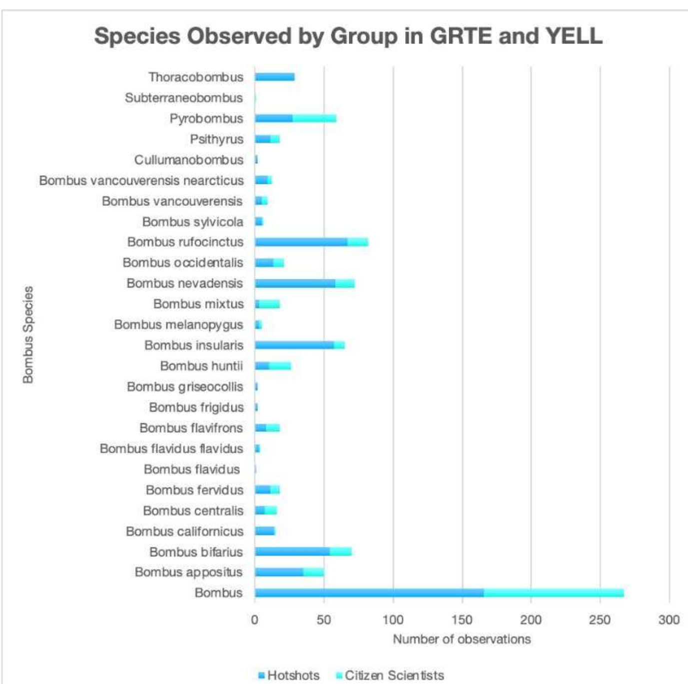


Figure 3: The quantity of species observed in Grand Teton and Yellowstone National Parks. These are broken up by whether the observation was made by a Pollinator Hotshot or a citizen scientist.

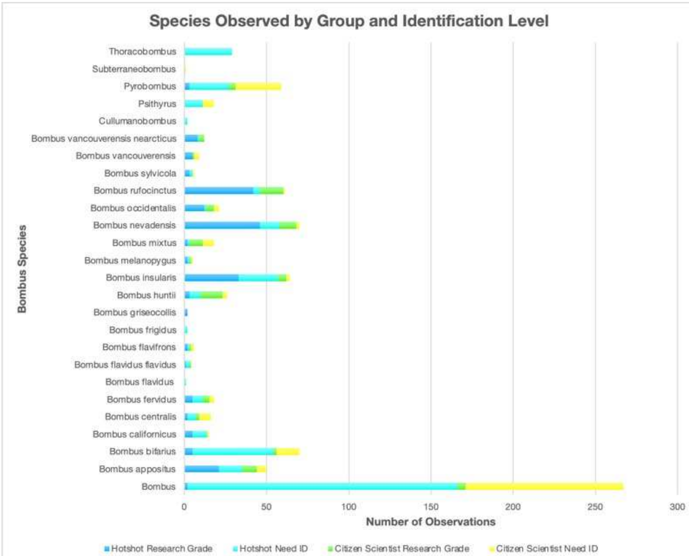

Figure 4: The quantity of species observed in Grand Teton and Yellowstone National Parks. These are broken up by whether the observation was made by a Pollinator Hotshot or a citizen scientist and whether the observation is research grade or needs ID.

*GRTE*

In GRTE there were a total of 24 taxonomic groups observed. These included 1 genus, 3 subgenera, and 18 species and 2 subspecies. The genus observed was *Bombus,* and the subgenera included *Psithyrus*, *Pyrobombus*, and *Subterraneobombus*. The 18 species observed were *Bombus appositus, bifarius, californicus, centrallis, fervidus, flavidus, flavifrons, frigidus, griseocollis, huntii, insularis, melanopygus, mixtus, nevadensis, occidentalis, rufocinctus, sylvicola,* and *vancouverensis.* There were also two subspecies observed including *Bombus flavidus flavidus* and *Bombus vancouverensis nearctisus.*

*YELL*

In YELL there were a total of 23 taxonomic groups identified. Of these, one was the overall genus *Bombus*, 4 were subgenera, 17 species, and one subspecies. The four subgenera included *Psithyrus, Pyrobombus, Cullumanobombus,* and *Thoracobombus.* The 17 species observed by the iNaturalist users and/or the Hotshots were *Bombus appositus, bifarius, californicus, centralis, fervidus, flavifrons, frigidus, griseocollis, huntii, insularis, mixtus, melanopygus, nevadensis, occidentalis, rufocinctus, sylvicola,* and *vancouverensis.* The one distinct subspecies observed was *Bombus vancouverensis nearctius.*

*Observers Across Parks*

Between the parks, different species were observed by different groups and at different identification levels (Table 1). The Hotshots observed 3 species (*Bombus flavidus, Bombus frigidus* and *Bombus griseocollis*) and 2 subgenera (*Cullumanobombus* and *Thoracobombus*) that the citizen scientists did not observe. The citizen scientists, however, did make observations of species within these genera meaning that the observations may not be unique to the Hotshots. The citizen scientists identified 1 genus (*Subterraneobombus*) that the Hotshots did not observe, but the Hotshots did observe a species from this genus, meaning that the identification that the citizen scientists made may not be unique.

Table 1: The check marks indicate that the taxonomic group was indicated by the group and with the identification level. The X mark indicates that it was not observed by a given group at that identification level.

Table 1: Species Observed in GRTE and YELL by Group

| Combined Park Species | Hotshot RG | Hotshot NID | CitSci RG | CitSci NID |
|---|---|---|---|---|
| *Bombus* | ✓ | ✓ | ✓ | ✓ |
| *Bombus appositus* | ✓ | ✓ | ✓ | ✓ |
| *Bombus bifarius* | ✓ | ✓ | ✓ | ✓ |

| | | | | |
|---|---|---|---|---|
| *Bombus californicus* | ✓ | ✓ | X | ✓ |
| *Bombus centralis* | ✓ | ✓ | ✓ | ✓ |
| *Bombus fervidus* | ✓ | ✓ | ✓ | ✓ |
| *Bombus flavidus* | X | ✓ | X | X |
| *Bombus flavidus flavidus* | ✓ | ✓ | ✓ | X |
| *Bombus flavifrons* | ✓ | ✓ | ✓ | ✓ |
| *Bombus frigidus* | X | ✓ | X | X |
| *Bombus griseocollis* | ✓ | X | X | X |
| *Bombus huntii* | ✓ | ✓ | ✓ | ✓ |
| *Bombus insularis* | ✓ | ✓ | ✓ | ✓ |
| *Bombus melanopygus* | ✓ | ✓ | ✓ | ✓ |
| *Bombus mixtus* | ✓ | ✓ | ✓ | ✓ |
| *Bombus nevadensis* | ✓ | ✓ | ✓ | ✓ |
| *Bombus occidentalis* | ✓ | ✓ | ✓ | ✓ |
| *Bombus rufocinctus* | ✓ | ✓ | ✓ | ✓ |
| *Bombus sylvicola* | ✓ | ✓ | X | ✓ |
| *Bombus vancouverensis* | ✓ | X | ✓ | ✓ |
| *Bombus vancouverensis nearcticus* | ✓ | ✓ | ✓ | X |
| *Cullumanobombus* | X | ✓ | X | X |
| *Psithyrus* | X | ✓ | X | ✓ |
| *Pyrobombus* | ✓ | ✓ | ✓ | ✓ |
| *Subterraneobombus* | X | X | X | ✓ |
| *Thoracobombus* | X | ✓ | X | X |

There were 111 users who contributed to the CitSci data on iNaturalist in GRTE, and 75 crowdsourced observers of *Bombus* species in YELL. There was a total of 186 citizen scientists who made *Bombus* observations between GRTE and YELL. Of the 186 observers, 14 individuals made *Bombus* observations within both parks.

Quantity of Observations

Between the Hotshots and citizen scientists there was a drastic difference between the total number of observations made. Overall, between both parks and observer groups there were 886 *Bombus* observations made between 2016-2022. 600 were made by the Hotshots, and 286 were made by the citizen scientists. This means that the Hotshots contributed 68% of the observations between the parks. The data seems to indicate that the hypothesis was supported that the Hotshots would collect more data than the citizen scientists.

Quality of Observations

The data accuracy of each group was measured by the percentage of the group's observations by species that achieved Research Grade on iNaturalist (Figures 5 & 6). Of the Hotshots' overall observations, 43.8% were research grade. 44.6% of the citizen scientists' observations were research grade.

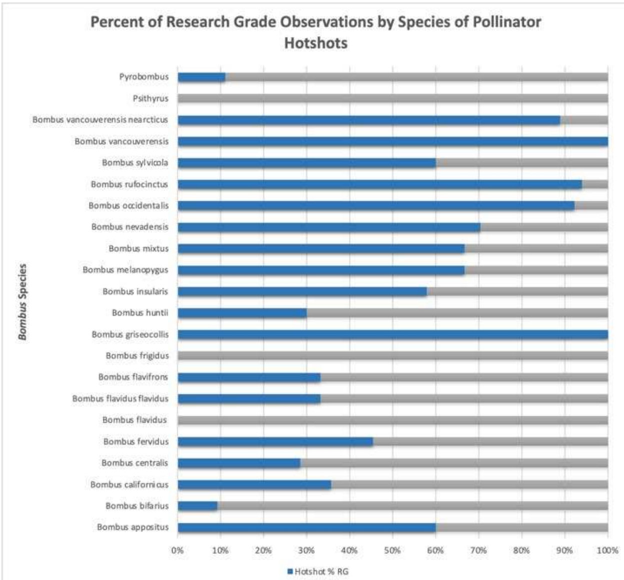

Figure 5: The percent of Research Grade observations made by the Pollinator Hotshots. This indicates the ratio of research grade vs. need ID observations of each species observed by the Pollinator Hotshots.

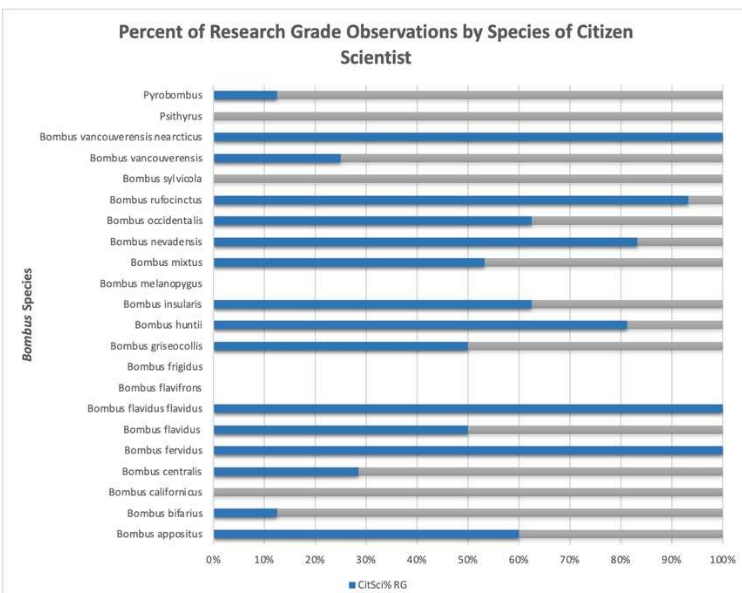

Figure 6: The percent of research grade observations made by the citizen scientists. This indicates the ratio of Research Grade vs. need ID observations of each species observed by the citizen scientists.

The Shapiro-Wilk test indicated that the Hotshot percentage was not normally distributed (p-value: 0.05748), while the citizen science percentage was (p-value: 0.01972). Because of the non-normal distribution of the Hotshot data, a Mann Whitney U test (Wilcoxon rank-sum) was conducted to determine if there was a significant difference between the averages of each group. The Mann Whitney U test indicated that there was not a significant difference between the percentage of research grade observations made by the Hotshots and the Citizen Scientists (p-value: 0.9735) (Table 2). This means that the hypothesis, that the Hotshots would collect significantly more accurate data due to their *Bombus* expertise, was not supported.

Table 2: This table indicates the statistical results of the tests for percentage of Research Grade observations made by the Pollinator Hotshots and the citizen scientists. The Shapiro-Wilk normality test indicates that the Pollinator Hotshot data is not normally distributed while the citizen scientist collected data is. The Mann Whitney U test with Wilcoxon correction indicates that there is not a significant difference between the percentage of Research Grade observations made by each group.

| Statistics Test Results |
|---|
| **Average % Research Grade for Pollinator Hotshots: 43.8%**<br>**Average % Research Grade for Citizen Scientists: 44.6%** |
| Shapiro-Wilk normality test<br><br>data: HotshotPercentRG<br>W = 0.91411, p-value = 0.05748 |
| Shapiro-Wilk normality test<br><br>data: CitSciPercentRG<br>W = 0.90144, p-value = 0.01972 |
| Wilcoxon rank sum test with continuity correction<br><br>data: HotShotPercentageRG and CitSciPercentageRG<br>W = 260.5, p-value = 0.9735<br>alternative hypothesis: true location shift is not equal to 0 |

Identifiers

The identifiers were people on iNaturalist who offer ID suggestions after an observation has been uploaded. There were 72 identifiers between the two parks.The identifiers varied significantly in who they are and how much they are making identifications. The most prominent identifier (johnascher) identified 647 species between GRTE and YELL. The following two most prominent identifiers made 171 and 153 identifications. This identification rate was not common among most identifiers. 59 of the 72 identifiers made 5 or fewer identifications, 44 of which made only 1 identification. This indicates that a small number of identifiers are making the vast majority of identifications within the parks.

## Discussion

### Quantity of Observations

The first hypothesis was that the Hotshots would collect more data than the citizen scientists as a result of their standardized data collection methods and large amounts of time spent in the parks. The Pollinator Hotshots, a group of roughly 5-10 people per year, made 68% of the *Bombus* observations in GRTE and YELL. This indicates that this group of between 35-70 people collected more than double the amount of data as a group of 113, supporting the hypothesis.

The Hotshots are using protocols that are standardized and targeted to achieve high rates of observation. They also dedicate significant amounts of time in the field to making pollinator observations. They survey for hours every day for several weeks every summer. This amount of time is more than most people spend in a National Park, meaning they have more time to make more observations per person.

### Quality of Observations

The second hypothesis was that the Hotshots would collect significantly more accurate data, defined by the achievement of Research Grade status for an observation, than the citizen scientists. The quality of *Bombus* observations, measured by the percent of research grade observations, did not differ significantly between the Hotshots and citizen scientists. It is important to note that if an observation does not achieve RG status it does not mean that the identification was wrong. It only indicates that it could not be corroborated by other users, likely due to unclear images.

The lack of a significant difference between the percentage of RG observations between the Hotshots and citizen scientists carries huge implications. First, it highlights the validity of citizen science data. It supports the idea that citizen scientists are capable of collecting data that is comparable to that of experts. Because of the research grade feature, iNaturalist has a built-in way to validate data making it more reliable without relying on experts to sort through all the data.

*Bombus* species are notoriously difficult to identify because of specific markers on different parts of the body that distinguish species. If a platform like iNaturalist allows novices to contribute meaningful identifications of difficult species, it indicates that it can allow for identifications across taxa.

## Identifiers

The identifiers vary drastically in the amount that they make identifications. It is evident that a select few identifiers are making the vast majority of identifications. Without these identifiers, there may be significantly fewer research grade observations confirmed on iNaturalist. This indicates the importance of identifiers on iNaturalist. They are what allows for data to be validated, and subsequently be seen as reliable.

## Limitations

The hotshots corroborate a lot of their own data, meaning the 'research grade' status may be self-fulfilling to some degree. They are trained in taxonomic identification but are all representative of one group. The rest of the users on iNaturalist receive species suggestions from others on the platform which likely includes members outside of their peers. Of the Hotshot's RG *Bombus* observations between both Parks, however, there is only 1 identification disagreement. This occurred when one of the Hotshots posted an observation with the identification of *Bombus californicus* and 3 others identified it as *Bombus occidentalis.* This image was made more difficult to identify because it was taken of a bee mid-flight, with bright purple flowers in the background (Figure 7). Because they still require one additional corroboration, usually from someone outside of the Hotshots, the impact of these self-fulfilling identifications may be negligible.

Figure 7 (iNaturalist, 2020): An image of a bumble bee that the Hotshots misidentified and was corrected by an identifier on iNaturalist.

Although the limited number of accounts increases the accuracy with which one can attribute an observation to the Hotshots, it also prevents one from knowing who among the Hotshots made the observation. I cannot determine the identification accuracy or number of 'Research grade' observations of any one Hotshot member. This prevents direct comparisons between individuals among the Hotshots and crowdsource participants.

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# Chapter 3: Reflections and Recommendations

## Citizen Science

This research sought only to assess the quality and quantity of *Bombus* observations in Grand Teton and Yellowstone National Parks. This research could be expanded in several ways in the future to gain a more cohesive understanding of the contrasts between expert and novice research. One method for expansion is to assess different species. *Bombus* species can be difficult to identify because of the slight differences in appearance across species, and different taxonomic groups tend to have a varying ease of identification. Accuracy among both citizen scientists and researchers may be different across species. Does citizen science become more accurate when identifying specific taxa or taxonomic groups? Are they more accurate in identifying more common or larger mammal species? These questions would help build a more cohesive picture of overall citizen science accuracy.

Another aspect to look at might be a comparison of different locations or kinds of locations. This study focused specifically on observations in Grand Teton and Yellowstone National Parks. Would these trends remain consistent across different National Parks? This could also be expanded to state or local parks. National Parks are places that the average person spends less time in than the area in which they live. Citizen scientists may be making more observations in cities or urban areas, and could even be making more observations than researchers are in these locations. Furthermore, they could be more familiar with the species diversity of the area in which they live, which may impact the accuracy of their species identifications. Are quality and quantity of observations impacted by the kind of location in which the observation was made? These are both questions that seek to address the overall question of citizen science data accuracy.

Data Accessibility

The concept of data accessibility has evolved over recent years. More recently, recommendations for what data should be has expanded to include other elements outside being merely accessible. The Research Data Alliance argues for the use of the FAIR principle, stating that data should be findable, accessible, interoperable, and reusable. The concept of FAIR data was first published in 2016 (Wilkinson et al.) and has been gaining traction ever since. The basis of making data FAIR is to make it usable by researchers. This highlights the fact that making data available on a platform, or making it technically accessible, might not be making it truly usable.

The difficulty of finding data can impact who is able to use it. Part of making it findable is making the data markers consistent, so the same data point appears the same across the globe. For data to be truly accessible it should be retrievable, and ideally free. If data exists behind a paywall, it will inevitably make it inaccessible for some people. The interoperability of data is reflective of using a widely applicable language for the representation of knowledge. Data should be discussed and described in a standardized and consistent way. For data to be reusable the data usage licenses should be clear and the attributes of the data should be accurately and extensively described. All these attributes of what makes data usable indicate the complex nature of what was once simply called data accuracy. An assessment of the FAIRness of data across platforms would help indicate the degree to which this principle is being implemented.

iNaturalist

Citizen science platforms all have distinctly different data storage methods and data accessibility. It can range from the complete inability of the user to download data from the platform, to all the data being findable and downloadable. Some may even follow the FAIR principle. The accessibility of iNaturalist data is one of the things that sets the platform apart from others. The data is easily findable on the platform, and anyone is able to download and use the data. Despite the accessibility of the data, there is still room for improvement on the platform that would allow the data to be more accessible and usable. The iNat Forum documents published papers that use iNaturalist data (Phalan, 2023). In addition to this, it would be beneficial if there was a way to see how much of iNaturalist data is being accessed and used past its initial upload. With more than 140 million observations on iNaturalist as of June 2023, how much of the data is being used for research after it is observed? It is hard to tell how accessible the data actually is without seeing how and to what extent it is being accessed. Even elements as simple as the ease of navigating to the download page can impact the user's ability to utilize the data.

## Discussion

Citizen science and data accuracy are deeply interconnected. Citizen science is making huge contributions to the data available in the world, but the accuracy of it continues to be called into question. As a platform that allows a distinct way of verifying data, iNaturalist has a significant role to play in the quest to ensure that citizen science can be verified and can subsequently be seen as accurate. A framework like the FAIR principle can help ensure that data meets the standards that support usable and verifiable citizen science data.

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