Using citizen science to approach invasive species: a case study of an Early Detection and Rapid Response invasion program in the National Park Service

By
Parker Hopkins
University of Colorado at Boulder

A thesis submitted to the
University of Colorado at Boulder
in partial fulfillment
of the requirements to receive
Honors designation in
Environmental Studies
May 2019

Thesis Advisors:

Dale Miller, Environmental Studies, Committee Chair
Heidi Souder, Baker RAP
Joanna Lambert, Environmental Studies

Abstract

In practice, public land managers must constantly innovate and adapt to keep up with constantly changing issues and concerns associated with the public lands for which they are responsible. Having access to the most current and reliable information is critical to respond effectively to arising disturbances related to public lands. In an effort to increase civic engagement in National Parks, new management and information-gathering methods are being embraced, such as citizen science. Technology has greatly aided in gathering more information to match demands, as projects and tools for citizen science are continuously in development, building a community of passionate amateur scientists and observers to provide useful contributions. Many different types of valuable information can be collected from citizen scientists, but in this study I focus on internal National Park Service (NPS) impressions of usability and the value of citizen science within the NPS. The discussion reviews an application to invasive species that may be of use to land managers when attempting to track invasive vascular plants within terrestrial units of the National Park Service. To achieve this, I distributed surveys to colleagues within the National Park Service and organized projects within iNaturalist, an application that collects information on the biodiversity of all taxonomic groups, which filtered observations by previously treated species within the NPS and subregions. To supplement discussion, I also conducted interviews within the NPS regarding the feasible use of citizen science. Results demonstrate that there is considerably positive valuation of citizen science from the National Park Service perspective. In fact, passive, un-encouraged observations of invasive vascular plants on iNaturalist number well over 10,000 across all units of the national parks. The presence of this large source of data gives merit to citizen science as a powerful way to collect significant amounts of cost-effective information, enabling an expedient response to

invasive species with a treatment practice known as early detection and rapid response (EDRR). The discussion supplements our findings by analyzing methods to make citizen-collected information actionable on the land manager's behalf, and looks to the future of citizen science in national parks by taking a practical overview of our invasive species project and the results of it.

Preface and Acknowledgements

In most academia incorporating large-scale data collection using citizen science on public lands, there is often a presumption of greater value to management of additional resources or gains in essential knowledge of resources. I often feel that there is a large gap in information between the presumed applicability of the data gathered and its actual applicability. To help close this gap, actionable plans should be implemented to utilize gathered data and apply that data to conduct effective management on public lands. Through this study, I hope to examine the uses and applicability of citizen science, a broadly used and shockingly affordable information collection method, in our national parks to assist in determining land management courses-of-action. To do so, I choose invasive vascular plants as a target group of actionable species where data can be collected and simply analyzed. I supplement the discussion of the "actionability" and scientific acumen of citizen science in parks with groundbreaking surveys and interviews that dive into the agency's experience and desire to host citizen science data collection programs and events.

Altogether, this information is intended to help inform academics and public land management agencies on the perspectives and overall applicability of citizen science projects in places like our national parks.

For guidance and assistance on this project, I'd like to say thank you to a few individuals:

Dale Miller
Heidi Souder
Joanna Lambert
Terri Hogan
Kiersten Jarvis
Kriston Barnes
Jennifer Sieracki
Anika Bernstein
Natalia Philatova
Robert & Angela Hopkins

Table of Contents

Abstract i
Preface and Acknowledgements iii
Table of Contents iv
Introduction 1
Background 3
Invasive Species 3
Invasive Plants 3
The National Park Service 5
Citizen Science 10
Outreach 13
iNaturalist 14
Collaborative efforts between iNaturalist and partners 16
The National Park Service and Citizen Science 17
BioBlitz Events 17
Invasive Plants and Citizen Science 19
Open-source data from iNaturalist 22
Surveys 22
Interviews with NPS Staff 23
Results 24
iNaturalist 24
Survey 27
Citizen Science Impression Responses 30
Interviews 31
Further Analysis of Results 33
iNaturalist 33
Temporal Qualities of Observations 33
Geographic Distribution of Information in Parks 33
“Research Grade” 35
Surveys 36
Discussion 39
iNaturalist 39
Using data in a timely manner 39

The popularity of the platform 40
Bureaucratic hurdles 41
Relaying information for actionable directives 42
Formatting of projects to include treatment lists and priority watch lists 43
Survey Responses 44
Interviews 45
Applicability of the true data set that was collected from iNaturalist 45
Impressions about proper vetting processes in citizen science projects 45
Applying iNaturalist observations to on-the-ground invasive species management 46
Limitations 47
iNaturalist 47
Surveys 49
Conclusions 51
Implications 53
Appendix A: Reference content 55
Acronym Glossary 55
Survey Questions 55
Standard Interview Questions 57
Appendix B: Additional Images, Figures, and Graphs 59
Bibliography 63

Introduction

Issues that land managers face are often varied and challenging in nature, as many concerns arise quickly and present unique obstacles that require elaborate solutions. The **National Park Service** (NPS), which stands to preserve some of the United States' most important natural, cultural, and economic resources for the enjoyment of this and future generations, is one such land management agency that responds to complex matters among its responsibilities. **Invasive species**, specifically invasive vegetation, are one such tumultuous concern that threatens integral resources and value of parks within the NPS. As such, it is important that NPS administrators are constantly looking for new, creative solutions to assist in problem solving with invasive vegetation.

With increased accessibility of technology in the twenty-first century, it became increasingly viable to engage citizens in collecting vital information about public lands, including data about resources and specific threats to those resources. **Citizen science** is an often underutilized method that encourages the public to help collect large volumes of information by conducting simple methodologies. The NPS has embarked on multiple prospective projects to investigate the utility of citizen-collected data and capacity for citizens to collect extensive information about the environment. Namely, the NPS invested in large-scale BioBlitz events once per year in the countdown to their 2016 centennial celebration. These large-scale **BioBlitz** events were efforts to involve communities around parks to engage with current scientific efforts and research within park boundaries.

In the latter years of the large-scale BioBlitz events, from 2014 to 2016, the NPS began to work with burgeoning technological projects such as **iNaturalist**, an ambitious effort by the California Academy of Sciences to collect open-source data on *all* taxa of organisms *anywhere*

on the planet, through the use of citizen science. Continuing the ambitious spirit of the BioBlitzes at the National Parks, this study continues to investigate the utility of iNaturalist and citizen science generally to achieve management goals and gain utility out of new technology. In conjunction with the NPS, I will look closely at citizen science and iNaturalist on public lands, their impact, and their utility going forward.

To collect information about citizen science in the NPS, I combine evidence from surveys, open source iNaturalist data, and interviews to more deeply analyze the future of citizen science data collection and its utility to help manage public lands. Data collected strictly looks at the NPS perspective, as compared to previous studies that evaluated the perspective of citizen scientists and their respective personal values and virtues that led to them aiding research efforts. As such, this study aims to analyze alternative data collection method to a well-established process among land managers that focuses on timely management of invasive species known as **Early Detection and Rapid Response** (EDRR) framework and walk through the development of a pilot program that encourages citizens to help 1) monitor and then 2) manage invasive plants in parks. Additional discussion focuses on the organizational structure of NPS invasive species response groups, including Exotic Plant Management Teams (EPMTs), who are split among 17 sub-regions of the National Park Service to manage invasive threats using the EDRR process.

Background

Invasive Species

Invasive Species pose a threat to worldwide biodiversity, as many sources have confirmed. The International Union for the Conservation of Nature's (IUCN's) Classification of Direct Threats indicates that Invasive species stand as one of the most critical threats to biodiversity, as indicated in a 2008 study published in *Conservation Biology* (Salafsky et. al., 2008).

The challenges that come with invasive species are not anticipated to get any better with emerging change in global systems. Climate change and other extreme events will exacerbate disturbances in ecosystems, and create opportunities for new invasive species to gain ground (Hellmann et al., 2008). Anthropogenic influences on the environment (not including climate change and the effects thereof), such as greater regional and global travel, will also exasperate the damages from invasive species in the future (Salafsky et. al., 2008).

Invasive Plants

Invasive animals often receive a lot of attention for their negative impacts on native or endemic ecosystems, but invasive plants oftentimes have a slower, but more impactful effect on native ecosystems and natural processes. Invasive plants pose a hefty threat to public lands and other protected ecosystems within the United States, with an incalculable economic effect on natural resources that are held within the public domain.

Because of the potential economic losses and the threats invasive plants pose to ecosystems and resources on public lands, invasive plant management is incorporated into

almost all long-term public land management strategies (Allen, 2009). It is estimated that about $1.3 billion of the federal budget each year is dedicated to invasive species prevention management across the United States (US Department of State).

Recent advances in the field of exotic plant management and control have aided efforts to prevent and manage invasions across the United States. Most efforts focus on database creation and management and focus on the spreading and formatting of information pertaining to invasions so that treatment can be as targeted and efficient as possible. Some of these solutions solely focus on efficient methods of gathering data, while others look to create protocols and standards to be adopted so that information can be shared more easily. (Simpson et al., 2008)

Early Detection and Rapid Response (EDRR) is an extremely popular method in use among land managers worldwide. EDRR utilizes two obvious components to implement a smart management strategy encouraging efficiency and logical choices among treatment opportunities. Early detection emphasizes the role of surveying and spotting invasive species, mapping them with points and polygons and making that information available to land managers as soon as possible. Rapid response describes an immediate follow-up treatment to an early-detected occurrence of an invasive species. Usually, rapid response takes the form of "strike teams," whose purpose is to address early detections of invasive species within a region that they are responsible for. The whole idea aligns with the common saying "an ounce of prevention is worth a pound of cure," as extinguishing a threat quickly is a much more effective management plan than battling a large-scale invasion (Westbrooks, 2011).

The effectiveness of EDRR has been tested by multiple studies, confirming that with proper procedures and communication, early detection and rapid response can be a successful venture and a worthy investment (Kaiser and Burnett, 2010; Simpson et al., 2018).

Federal agencies, as well as state, and local organizations have all attempted to address invasive species with various approaches, resulting in varying degrees of success. EDRR continuously grows as a popular method among all levels of government for effective control and treatment of invasive plants (Pimentel et al., 2000).

The National Park Service

The National Park Service (NPS) has managed America's most treasured natural spaces since its creation in 1916. In NPS founding legislation, the essential role of the agency is outlined as follows: “the Service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments and reservations…by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.” The NPS also plays an essential role in creating national environmental health and protection standards for public lands, as environmental degradation and abuse are more frequently reported on within NPS units. The NPS, therefore, has a role in developing common, logical resources that address key management objectives. The NPS, as a result, is an agency that finds itself responsible for a significant amount of land that needs to be protected from the threats of invasive species.

The NPS's mission is to "preserve unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations. The Park Service cooperates with partners to extend the benefits of natural

and cultural resource conservation and outdoor recreation throughout this country and the world."

Anthropogenic pressures on the environment consistently increase over time, as supplemental complexities emerge in many management scenarios across the Service. Invasive plant management fits into the heart the NPS mission, where the NPS preserves the natural and cultural resources of the land under its care. All federal agencies are also responsible to comply with congressional statutes and executive orders. A few of the statutes and executive orders specify invasive species as a priority threat to parks, and consider the control of invasive species a nonnegotiable management goal to be fulfilled by the NPS and other federal agencies.

Executive orders on invasive species have provided all primary guidance to agencies on the management of invasive species.

Executive Order 13112 of February 3, 1999 (on Invasive Species):

> *"called upon executive departments and agencies to take steps to prevent the introduction and spread of invasive species, and to support efforts to eradicate and control invasive species that are established. Executive Order 13112 also created a coordinating body -- the Invasive Species Council, also referred to as the National Invasive Species Council -- to oversee implementation of the order, encourage proactive planning and action, develop recommendations for international cooperation, and take other steps to improve the Federal response to invasive species. Past efforts at preventing, eradicating, and controlling invasive species demonstrated that collaboration across Federal, State, local, tribal, and territorial governments; stakeholders; and the private sector is critical to minimizing the spread of invasive species and that coordinated action is necessary to protect the assets and security of the United States (invasivespeciesinfo.gov). An additional order signed by President Barack Obama amends Executive Order 13112 and directs actions to continue coordinated Federal prevention and control efforts related to invasive species. The new order maintains the National Invasive Species Council (Council) and the Invasive Species Advisory Committee; expands the membership of the Council; clarifies the operations of the Council; incorporates considerations of human and environmental health, climate change, technological innovation,*

and other emerging priorities into Federal efforts to address invasive species; and strengthens coordinated, cost-efficient Federal action (Department of State).”

Among the institutions that lie within the NPS, invasive plant management efforts can be directed from many different levels within the overall organization. There are a few exceptions to which all parks must comply with certain invasive plant reporting and management efforts. (Wagner et. al., 2017) For example, all organizational levels must use the Pesticide Use Proposal System (PUPS) to confirm and authorize the use of herbicides within NPS boundaries.

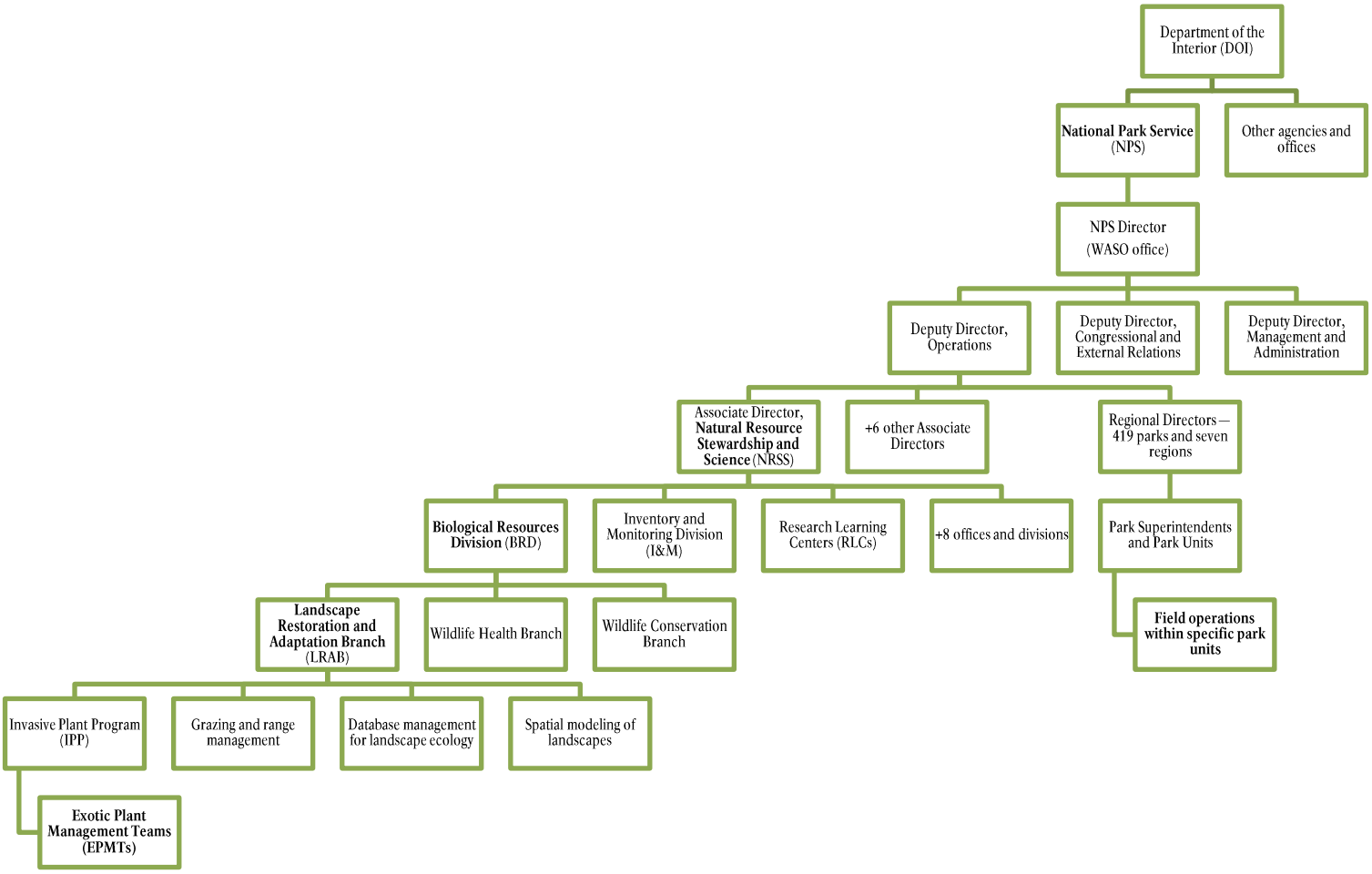
Some invasive plant management occurs within individual NPS units, where staff volume and infrastructure are sufficient to support a team of exotic plant managers, who focus on treatments within their host park's boundaries. These teams will often be localized and within larger parks of the NPS, such as Yellowstone, Yosemite, or Grand Canyon.

A larger organizational structure for invasive species management is controlled at the nationwide level of the NPS, out of the Washington D.C. office. Control of invasive species programs at a higher level enables tactical coordination of invasive vegetation management within the NPS.

Within the organization of the director's office of the NPS, teams are controlled through the Natural Resource Stewardship and Science Directorate (NRSS). The NRSS “provides scientific, technical, and administrative support to national parks for the management of natural resources. NRSS develops, utilizes, and distributes the tools of natural and social science to help the NPS fulfill its core mission: the protection of park resources and values (National Park Service).” NRSS maintains staff and offices in Washington, DC, Lakewood, Colorado, and Fort Collins, Colorado.

Within the NRSS, invasive plant management is that manage through the Biological Resources Division (BRD). Very similar to the NRSS mission, the BRD "provides Service-wide perspective, expertise, and leadership in developing and communicating biological resource science and policy, and identifying and implementing new approaches to biological resources stewardship to help the NPS fulfill its core mission: to preserve unimpaired the natural resources and values of the National Park Service for the enjoyment, education, and inspiration of this generation and future generations (National Park Service)." The NPS's BRD maintains its offices in Fort Collins, Colorado. The BRD is organized into three branches, each of which has a unique and separate role. Those branches are the Wildlife Health Branch, who manages wildlife pathogenic and human health concerns, the Wildlife Conservation Branch, who prioritizes protecting habitats and ecosystems critical to wildlife across the NPS, and the Landscape Restoration and Adaptation Branch.

The Landscape Restoration and Adaptation Branch (LRAB) assists to manage many different aspects of the NPS mission, from creating resources for pest management in parks to overseeing livestock grazing operations in parks that were designated for it. One of the largest components of LRAB's duties, however, is the management of invasive species. LRAB oversees the NPS Invasive Plant Program (IPP), conducting outreach, coordinating meetings, providing guidance and expertise, performing research, and staying up-to-date on recent advances in theory and practice. Included in the IPP is the oversight of the nationwide Exotic Plant Management Team (EPMT) program.



EPMTs perform surveying and treatments across almost all units of the NPS, offering extremely valuable data collection and invasive species control efforts for parks. EPMTs often perform the role of strike teams, taking early action on invasions that would adversely affect ecosystems that have vital natural and cultural resources to the Park Service (Marris, 2005). Overall, EPMTs form 17 Regional Teams that cover anywhere from 5 to 25 parks each. The structure and capacity of each EPMT is variable, by region, mostly because each of the 17 regions has different seasons, needs, budgets, and invasive species to address.

The model that EPMTs generally follow originated in Lake Mead National Recreation Area during the early 1990s, where a platform was developed to rapidly respond to new invasive threats within the confines geographically close units of the NPS, by mobilizing a team of

invasive plan managers to promptly deal with a threat and contain its effects on the surrounding environment. Since then, EPMTs perform their function throughout the NPS as primarily invasive vegetation management crews, although teams also pursue inventory and monitoring duties.

A good general rule to apply to all regions, however, is that they all function as "strike teams" that 1) strategize treatments for optimal species at optimal times and 2) prioritize the EDRR method.

Strike teams have costs that are associated with logistical availability and fluidity. These vary by teams and by locations that warrant responses. EDRR methods vary based on targeted species and invasions magnitude and rate of growth. (Minor and Gardner, 2011)

Citizen Science

Citizen science is an often-underutilized tool to gather valuable information that can be used in research and monitoring programs. Taking a step back, citizen science more generally is a process that utilizes volunteers who wish to contribute to a study as amateur scientists and data collectors. As Theobald et al. (2015) identified, citizen science is a viable, cost-effective tool to approach management concerns of the “evil quintet”: climate change, overexploitation, invasive species, land use change, and pollution.

One study has successfully defined the effectiveness of citizen science as a data collection method. In the study, it was understood that citizen science had costs, benefits, and limitations; however, there are a few key instances where citizen science was an excellent method to take data in a wide range of geographic areas and to assemble that information to suit the core needs of stakeholder agencies (McKinley et al., 2017).

There are already a few notable examples of long-running citizen science projects in the United States, that have been able to make effective use of information to inform both academics and governmental entities. McKinley et. al., discussed a few exceptional examples, and a few technologically exceptional examples are discussed further in the Background.

There have been varieties of ways to use data collected from citizen science, from its general metadata capturing to its extensive collection capacity over short periods of time (Dickinson et al., 2012). Long-running projects that are considered successful have several commonalities among them. First, successful projects tend to have extensive outreach efforts associated with the program; second, these projects will have a consistent usership who checks in on findings and data gathering; third, a successful program generally has the backing/support of the scientific community that would generate utility from findings.

Additionally, there have been significant recent advances in utilization of technology when collecting citizen science data, including use of mobile phones and other more accessible tools developed in an effort to bring citizen science closer to the citizen scientists that contribute to data collection (Graham, 2011). One impressive feature that technological advances have brought to citizen science data collection is how easily and precisely geographic information can be gathered (Haklay, 2013). The collection of this broad amount of geographic information enables scientists to apply findings with much greater accuracy and increased certainty related to citizen science observations.

The following is a list of notable citizen science projects that have widespread utilization of technology and a considerable user base and/or relevancy to land management.

- Project Noah

Project Noah is and ongoing experiment in the collection of all-taxa information on an international scale that has already notably impacted the citizen science community. With support from the National Geographic Society, Project Noah stands as an exceptional mobile tool to collect information on all types of organisms. The NPS's BioBlitz events endorsed the use of Project Noah during the 2012 and 2013 BioBlitz events until an official Task Agreement with iNaturalist enabled the NPS to create tools and features in a comparable all-taxa citizen science data collection platform, incentivizing the transition over to the new project.

- Plant Snap

Plant Snap is a tool created to use machine learning to enable others to identify common plant specimens that occur in the natural world around them. As mentioned, Plant Snap utilizes existing photos of plant specimens to enable machine learning to identify the plants that exist in the world. Data are not as accessible as data collected on iNaturalist or other platforms listed, and no major academic papers have been published using data collected on plant snap.

- WildSpotter

WildSpotter is a new invasive species monitoring application developed by the United States Forest Service (USFS), which similarly also has its own mobile application. WildSpotter was released in mid-2018 and is currently conducting a pilot project at 13 different national forests. Implementation to a broader scope of wild spaces may happen in an order of years, so results are yet to be seen. WildSpotter observations are run through EDDMapS, which is explained later in the Background section.

- NPS attempts and early development

The NPS began the early stages of an investigation to develop a citizen science data collection application of their own, where they could control all aspects of the application. These plans were scrapped relatively early in their development, and no information has been published on the attempt (National Park Service, 2014).

Outreach

For a citizen science project to be successful, there must be a continuity of outreach from a central organizing platform, to continue and encourage amateur scientists to contribute to the study or data being collected. By ensuring a continuous source of outreach, and continuous updates and feature improvements on the platform, there can then be a continuity of data collection. One challenge that many studies have brought to light is that they have trouble retaining citizen scientists and volunteers after initial participation into a study or project. A few suggestions have been made in academia to 'retain the audience,' thereby retaining continuity in the citizen science efforts.

For close to a decade, verification methods have been used commonly among citizen science projects. In general, a decent amount of professional human workforce capacity is required to verify observations that have been made throughout the time of observations in the parks. Past efforts for verification have led to the creation of new platforms, such as the Early Detection Distribution and Mapping System (EDDMapS) out of the University of Georgia. Systems such as EDDMapS can properly process information that comes in over the course of an event or project (Cronje et al., 2011).

iNaturalist

Convenience is important for iNaturalist to become a readily accessible and consistently useful tool. There have been continuous improvements and additions to the program to improve its ease-of-use, including improved mobile applications, user interfaces, and system functionality. Graham et al. (2011) identified that these types of improvements to the data-collection process make identifications and continued participation in citizen science more likely. More recently, machine learning and artificial intelligence have enabled the development team of iNaturalist to automate the identification process (Van Horn et al. 2017), providing recommendations and making the process and enormously easier for non-taxonomists. Because of this, iNaturalist offers a good platform to engage citizen scientists, and the NPS organized a contract with the continuously improving program as part of its 2016 Centennial Celebration. iNaturalist was formally used and endorsed during large "BioBlitz" events across the country, where all-taxon inventories were conducted with large groups of volunteers and experts in ecology. Efforts have continued in the NPS to use iNaturalist for inventories and engagement, often through small, organized events by local park staff. Attempts are also made to integrate iNaturalist data sets into NPS inventorying systems such as the Integrated Resource Management Applications (IRMA) system. The NPS hopes to continue to work with iNaturalist to educate and engage visitors, as well as collect valuable data that can be used for different management actions and decisions.

Many different methods have been suggested to pilot invasive species monitoring programs on public lands. Of those opportunities, the NPS has pursued opportunities to collect data on biological resources by contracting with a program, developed at the California Academy

of Sciences, called iNaturalist. iNaturalist offers a free, open-source, multi-platform suite of clients and applications to record biota of any taxonomic grouping (Nugent, 2018).

On iNaturalist's website they define their history as follows:

> *"iNaturalist.org began as the Master's final project of Nate Agrin, Jessica Kline, and Ken-ichi Ueda at UC Berkeley's School of Information in 2008. Nate and Ken-ichi continued working on the site after graduation, with some additional help from Sean McGregor. Ken-ichi began collaborating with Scott Loarie in 2011, when they organized as iNaturalist, LLC and began expanding the site through numerous collaborations. In 2014 iNaturalist became an initiative of the California Academy of Sciences and a joint initiative with National Geographic Society in 2017 (iNaturalist, 2019)."*

iNaturalist is a large-scale project based on observations and identifications where a community of amateur scientists can record their findings in the outdoors and upload them for analysis online (Nugent, 2018; Van Horn et al., 2017). Convenience is key for iNaturalist, as there have been continuous improvements and additions to the program that improve its ease-of-use, as referenced earlier. Because of this, iNaturalist offers a good platform to engage citizen scientists, and the NPS organized a contract with the continuously improving program as part of its 2016 Centennial Celebration. In all, over 1.2 million observations have been made since the platform's launch in 2008. This owes a lot of its credit to the process of using the mobile application.

Making an observation is simple. You must download the app on your smartphone, create an account, and start taking photos. Important information such as geolocation metadata, place names, time zones, and more is automatically recorded. The ease to collect integral information like this makes the entire operation relatively painless.

iNaturalist makes all of its features (on both mobile and browser platforms) easy-to-access, with the most essential features of the app being offered at the front-end user interface.

To make the process easier for naturalists and amateur scientists using the app, iNaturalist utilizes machine learning and image classification sets to provide suggestions and recommendations for identifications, which on the platform are known as "Computer Vision Suggestions." These ease-of-identification features make the taxonomic classification process simple for amateur scientists and naturalists who are looking to learn and become more versed in taxonomy. All data recorded on iNaturalist is straightforwardly downloadable in large batches through data exporting tools that are embedded in the website. Filters also enable users to find very specific observations and details of specimens that have been observed. iNaturalist, as a project, is funded through the California Academy of Sciences, making it a public institution and a public resource. This protects the program from exploitation and commercialization as features are added and the user base grows.

Collaborative efforts between iNaturalist and partners

iNaturalist has embarked on many relationships with other teams of researchers and large events to help grow its platform and notoriety as an organization. By working with other organizations, iNaturalist has been able to get funding to hire more staff, add new features, and add increased capabilities for the mobile application.

iNaturalist and National Geographic worked closely to produce the large-scale BioBlitz events that occurred once per year in the 10 year lead up to the NPS Centennial Celebration. During this time, National Geographic and the NPS provided funding to create integral components of iNaturalist such as the project system, blog features and news events, and more.

More recently, iNaturalist has teamed up with City Nature Challenge to create some of the largest citizen science events in history, occurring in hundreds of urban areas around the

globe for data collection programs that occur for days at a time. Together with the City Nature Challenge, the iNaturalist team has been able to develop improvements such as umbrella projects, collection projects, and has revamped pre-existing features such as the project page.

The National Park Service and Citizen Science

The NPS was an early adopter of citizen science as a way to engage the public. The NPS notes the value of citizen science on its website "For two reasons … good management of parks, and good experiences for visitors."

Citizen science can often function as a learning experience for visitors, as the website expands: "Citizen science is also a great way for visitors to enjoy and learn about their parks. In recent legislation, Congress affirmed an educational role for the NPS. Citizen science helps the NPS fill that role. One of the best ways to learn science is to do science. And by doing science, people can appreciate their parks in new ways. Amid the grand vistas sometimes it's nice to stop, focus on a small patch of ground, and count the number of flowers." The NPS continues to support citizen science efforts, as a result of its mission to educate visitors, build relationships, and search for potential practical land management uses of data.

BioBlitz Events

BioBlitzes are described by National Geographic as "an event that focuses on finding and identifying as many species as possible in a specific area over a short period of time. At a BioBlitz, scientists, families, students, teachers, and other community members work together to get a snapshot of an area's biodiversity. These events can happen in most any geography—urban,

rural, or suburban—in areas as small as a backyard or as large as a country (National Geographic Society)."

BioBlitzes are a huge tool that the NPS has used to create visibility for citizen science, and to celebrate education and engagement, they take it a step further by encouraging local school districts to bring out buses full of kids who are excited to learn and interact with the environment of their local national parks. From 2007 until 2016, the NPS and National Geographic teamed up to host large-scale 1,000+ participant BioBlitz events that engaged local communities, amateur scientists, and enthusiasts of the outdoors to collaborate and collect interesting information about parks and the life that lived within them during a 24-hour period of searching.

iNaturalist became involved in the BioBlitz events beginning at the 2014 Golden Gate National Recreation Area BioBlitz in San Francisco, California. iNaturalist served as a primary data recording tool for the whole BioBlitz that year, generating an output of species observed that stands as one of the largest BioBlitz events that were ever hosted, by species count. The relationship between iNaturalist, National Geographic, and the NPS continued to evolve for the next two annual BioBlitz events, culminating on the National Park Service Centennial in the last large-scale National Geographic-NPS BioBlitz as a nationwide event. In the lead up to the 2016 BioBlitz, a task agreement was signed between the NPS and iNaturalist that outlined teamwork between the two organizations until April 2020. Among the language in the agreement, it was included that iNaturalist would assist in NPS needs, data requests, feature additions, and more through the end of the task agreement.

Many feature additions, project assistance, presentation materials, multimedia, and outreach activities were produced because of this partnership around the 2016 National Park

Service Centennial. Most of the primary tasks that were outlined in the original agreement between the NPS and iNaturalist have been completed since 2016, yet the agreement still stands until April 2020 while a pending approval of a new task agreement is in the works (own source).

Among the tools that were built because of the task agreement is a presentation mode for projects, collections for projects themselves, mapping tools, graphical tools, user interface improvements, mobile features, and more subtle features of the program and web client.

An additional collaborative project between the NPS and NatureServe plans to report on data findings from the BioBlitz events, although it is yet to be published.

However, there is literature on the potential application of data collected during the BioBlitz events, where data are managed, shared, and distributed among parks to: update species lists, provide interpretive materials, serve as a reporting mechanism, and create new discoveries of threats within parks (Budde and Kingston, 2014; Crall, 2010). An end goal is outlined to eventually inform management plans within parks with data that is collected during BioBlitz and other citizen science events, although this information was only implicated, not necessarily followed up on.

iNaturalist is continuously used within the NPS, although new issues have arisen recently that will be discussed further in the limitations section. There are concerns regarding 1) the endorsement and liability of citizen collected information with potential private information attached and 2) endorsing federal employee usage of a third-party application.

Invasive Plants and Citizen Science

One consistent request from the invasive plant management community is for more data, both to inform public lands administrators, and to inform proper management actions (Bradley et

al., 2018). There have been multiple projects that target invasive species in the past, even those that have their own mobile interfaces. (Crall, 2012; Gallo and Waitt, 2011)

EDDMapS pro is an application that is developed by the Early Detection and Distribution Mapping System (EDDMapS) team, to specifically track invasive species from your mobile device. EDDMapS is a program run by the University of Georgia Center for Invasive Species and Ecosystem Health, and is currently supported by the United States Forest Service, the NPS, the US Fish and Wildlife Service, the US Army Corps of Engineers, and more governmental organizations. The user base for EDDMapS Pro is rather small, at 52,551 users. EDDMapS also does not have tools to specify where exactly in invasive species observation occurred, although you can download data on point reports of invasive species.

WildSpotter is a new invasive species monitoring application developed by the United States Forest Service (USFS), which similarly also has its own mobile application. WildSpotter was released in mid-2018 and is currently conducting a pilot project at 13 different national forests. Implementation to a broader scope of wild spaces may happen in an order of years, so results are yet to be seen. WildSpotter observations are run through EDDMapS, and depend on USFS experts to verify observations.

One persistent issue surrounds engaging the public to collect invasive species-related citizen science data. Many attempts and academic studies have been conducted that discuss the data gathering process and specific methods that particularly gain the attention and support of observers, as well as collect accurate and consistent data (Nov et al., Various). Robust outreach and communicative efforts have shown promise as ways to continuously engage citizen scientists, encouraging them to continuously try to learn and collect data for their scientifically disciplined project (Nov et al., Various).

The most successful programs for general citizen science data collection often involve a community of amateur scientist peers that build support off of one another for their project, and as a result continue to collect good information and maintain good methods throughout their data collection process. The social component of developing a community around citizen science is also a major draw for participants to continue their work (Gallo and Waitt, 2011).

Methodologies

This study aims to analyze the feasibility and policy implications for a citizen science-based monitoring and management program for the nationwide control of invasive species within the boundaries of NPS units. Data products will include interviews, survey responses, and plentiful open-access data that has been provided through the iNaturalist program.

iNaturalist

Data was collected from the iNaturalist program, whose data are open source, to be analyzed. A series of 32 projects modeled after the 32 Inventory and Monitoring regions of the NPS set parameters that will cross-reference the current NPS invasive species database, the National Invasive Species Information and Management System (NISIMS), to search for already known and reported invasive species within park boundaries. In addition, invasive plant managers of their respective EPMT regions of the NPS will be consulted for additional input on not yet present but threatening invasive plants, and those parameters will also be input into projects. This proof-of-concept is to demonstrate how citizen scientists already report on invasive species locations within National Park units.

Surveys

Surveys were sent out to NPS staff in select organizations within the larger NPS hierarchy, notably Research Learning Center Programs, the Biologic Resources and Inventory and Monitoring Divisions of the Natural Resource Stewardship and Science Directorate (NRSS) (Washington D.C. office), to ask them to reflect upon the use of citizen science. Questions generally covered the need for citizen science as a tool for outreach and management in National

Parks, and what potential interpretive and practical value that could be derived from the widespread establishment of citizen science programs. It was an anonymous survey hosted through Google Forms. Respondents were asked to answer questions as copied verbatim in Appendix A.

Interviews with NPS Staff

Casual interviews were conducted with NPS staff who work closely with invasive species data and who are involved in citizen science efforts across the parks. Questions generally reflected their feelings towards citizen science data collection and the usability of that data in making management decisions. Interviews were conducted with an open-ended format, to allow for advanced discussion on the merits and value of citizen science, only loosely following a set of simple questions (attached in Appendix A).

Results

Our three sources of information yielded an assortment of data that I will use to gain findings on the feasibility of an EDRR program in the National Park System. Surveys, interviews, and iNaturalist data are being used to test the efficacy of a citizen science-driven early detection and rapid response network across the network of all 417 units of the NPS. I will walk through the sources, starting with iNaturalist and then working through the survey responses. Interviews will be incorporated into the discussion section.

iNaturalist

Data collected on iNaturalist is, as described earlier, passively collected data by amateur naturalists and botanists whose interest generally lies in recording and identifying species. Overall, the project created in iNaturalist covers all 417 units of the NPS and identifies specific species that were treated by Exotic Plant Management Teams among 32 distinct regions of the country. Each of the 32 distinct regions covers between 3 to 12 units of the NPS. Out of the 500+ species treated in parks, over 300 were represented in collected data points. These range from extremely common findings, such as the Great Mullein (*Verbascum thapsus*), to more obscure, new threats, such as the Java Plum (*Syzygium cumini*). Over 11,500 observations were recorded in total, across all but a few units of the NPS. Since iNaturalist constantly records new observations and places them into collection projects, such as the one that was organized, it is guaranteed that almost every day the project will garner new observations of invasive species in parks.

Figure 1: iNaturalist invasive species projects, developed on iNaturalist conforming to the boundaries of the 32 different Inventory and Monitoring sub-regions of the NPS. Gray dots on this map indicate where observations have occurred, and the orange geographic areas on the base map indicate NPS managed units.

Table 1: Results from each of the 32 iNaturalist projects, ordered alphabetically by region.

Network	Observations	Species	Observers
Appalachian Highlands Network	127	26	70
Arctic Network	0	0	0
Central Alaska Network	0	0	0
Chihuahuan Desert Network	98	15	65
Cumberland Piedmont Network	217	95	75
Eastern Rivers and Mountains Network	123	30	49
Great Lakes Network	771	80	311
Greater Yellowstone Network	165	22	90
Gulf Coast Network	124	12	63
Heartland Network	1,044	82	270
Klamath Network	67	19	53
Mediterranean Coast Network	1,331	54	278
Mid-Atlantic Network	234	35	98
Mojave Desert Network	970	62	278
National Capital Region Network	6	4	4
North Coast & Cascades Network	264	31	124
Northeast Coastal and Barrier Network	177	9	76
Northeast Temperate Network	1,024	56	345
Northern Colorado Plateau Network	347	47	162
Northern Great Plains Network	145	21	56
Pacific Island Network	93	10	57
Rocky Mountain Network	166	24	84
San Francisco Bay Area Network	3,519	76	1,005
Sierra Nevada Network	65	20	45
Sonoran Desert Network	30	13	17
South Florida/Caribbean Network	182	44	62
Southeast Alaska Network	27	9	10
Southeast Coast Network	257	40	113
Southern Colorado Plateau Network	87	10	62
Southern Plains Network	63	25	27
Southwest Alaska Network	1	1	1
Upper Columbia Basin Network	13	10	10

Notable observations from the table include the San Francisco Bay Area Network, which by far controls the most observations and engagement. Also notable are the 5 different Alaskan subregions, whose remoteness from visitation and general isolation from pathways to invasion has left very few invasive observations.

Figure 2: Observations of iNaturalist projects within the Contiguous 48 states and the Caribbean.

Some regions out of the 32 I&M groups in the NPS had more observations than others, likely due to civic engagement and encouragement of the use of the iNaturalist app. For example, the San Francisco Bay Area Network had by far the most observations of the regions, likely because California Academy of Sciences is based in the Bay Area and has conducted extensive outreach to encourage usage of the app in local parks and preserves.

Surveys

Fifty-seven survey responses were received, from target organizations of the NPS largely from the Natural Resource Stewardship and Science Directorate (NRSS) within the Washington D.C. national office. Responses were collected over the course of about a week and a half, with the largest surge of responses coming the first 24 hours, while more responses trickled in during

the following 72 hours. Of all 57 responses, only two forms were left incomplete during the process of filling them out, fortunately meaning that there was a consistent response rate throughout the survey.

Within the NPS, respondents had equally sized and variable degrees of expertise among them, as more than 5 respondents had expertise in each of the 4 groups ranging anywhere from 0-20 years in the service. In addition, there were 4 respondents who had more than 20 years of experience in the NPS, with of those 3 respondents having more than 30 years within the Agency.

Respondents also have remained in their respective organizations of the NPS for an equal and wide range of times.

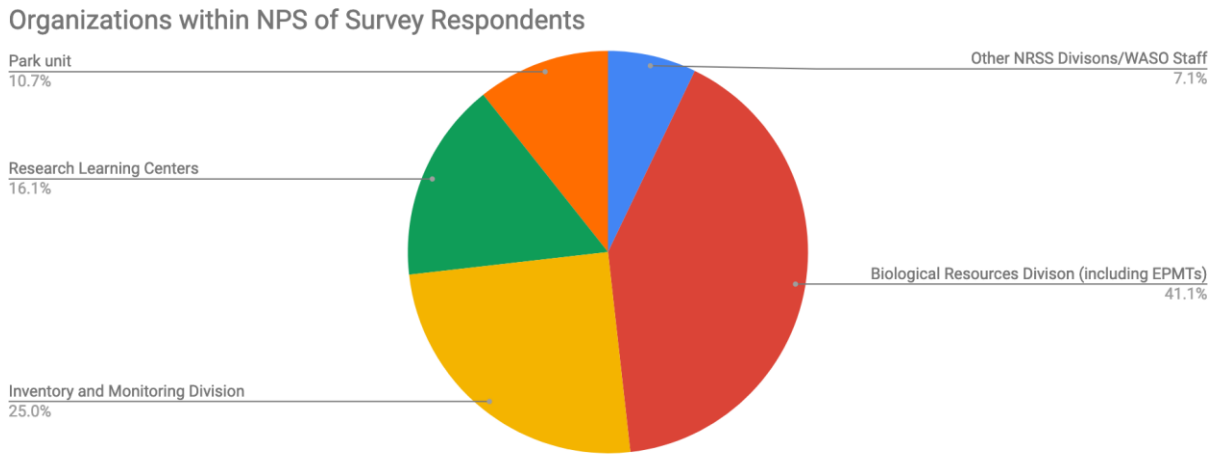


Figure 3: Respondents belonged to a wide variety of organizations within the park service, with different functions and roles; however, most of the respondents by far were from the Washington, DC office of the NPS, within the NRSS.

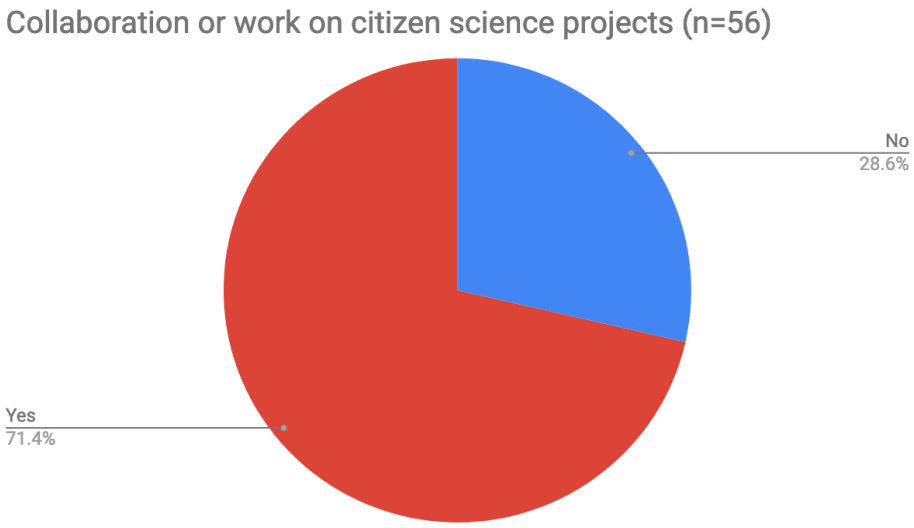


Figure 4: With a point spread of 42.8%, by far most respondents had organized or took part in a citizen science event in the past.

Citizen Science Impression Responses

For the most essential question of this study, just over half of respondents indicated that citizen science projects yielded usable land management data, with an additional fifth of respondents indicating that citizen science projects would yield negligible amounts usable data. Nearly a quarter of respondents indicated that citizen science does not provide usable land management data in their opinion.

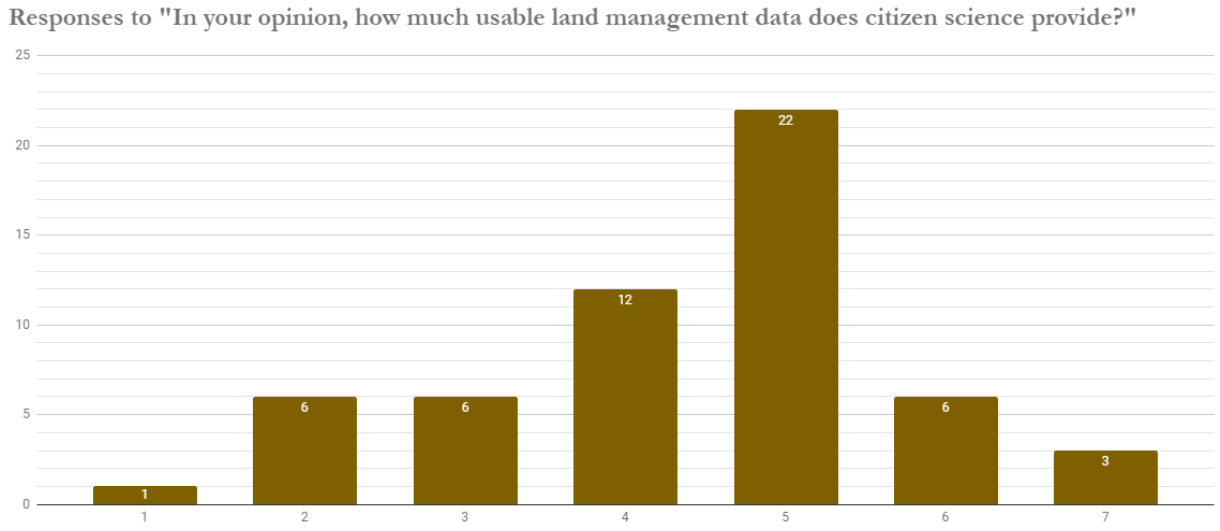


Figure 5: In this chart, responses more towards the right, or responses that are closer to seven, on the x-axis indicate that citizen science can provide significant amounts of usable land management data. The most popular response, at a ranking of five out of seven, indicates that respondents believe that there was some usable land management data collected from citizen science. It's notable that not mnany respondents believed that there was very significant utility of citizen science data to inform land management decisions.

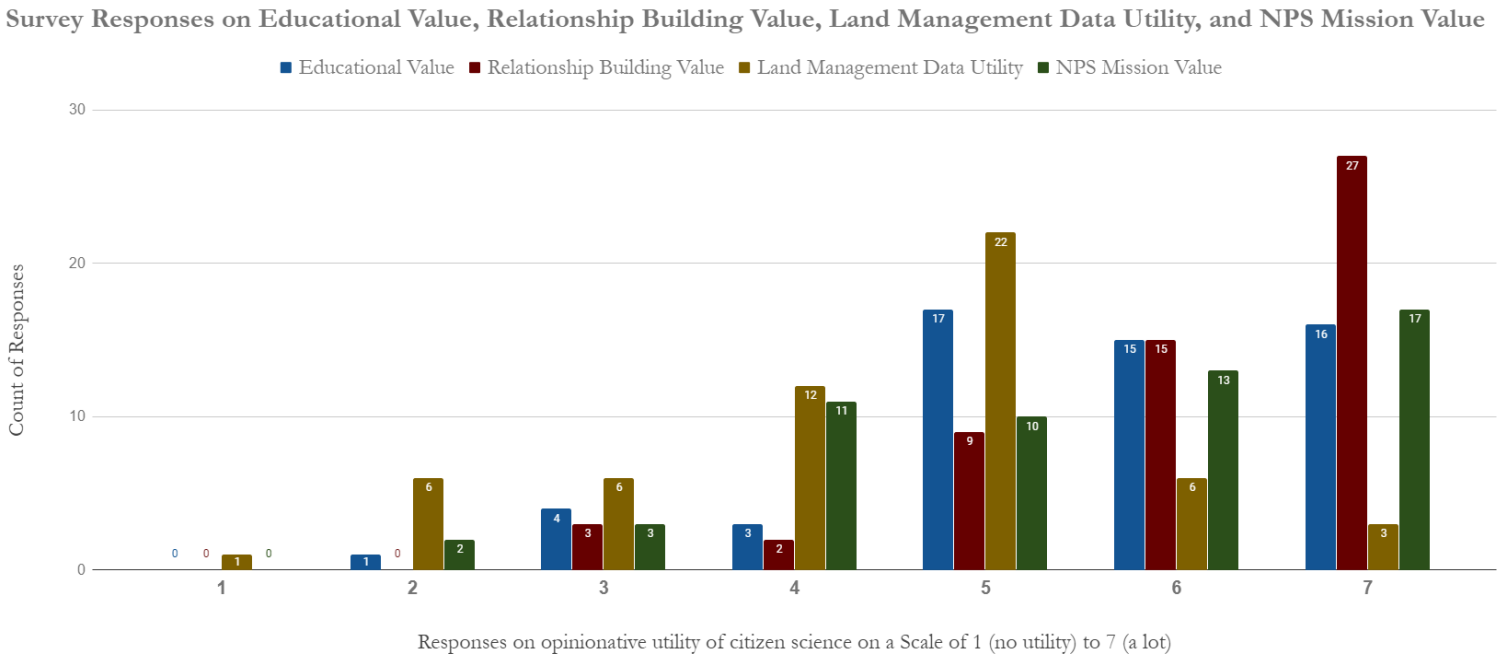


Figure 6: Other survey responses indicated that there is overwhelming value for using citizen science in educational settings (closer to seven on the chart), relationship-building settings, and in settings where citizen science can generally serve the NPS goals and mission. As is displayed in the graphic below, the responses from citizen science's ability to collect "usable land management data" stand out in the bar chart, as the largest count is five out of seven, just slightly above negligible utility. This trend is worth investigating further.

Interviews

In all, five interviews were conducted with NPS staff, diving into detailed questions that covered the use of citizen science in national parks, their history of work with citizen science, and specifically any work with iNaturalist if it were applicable with the interviewee. In addition, there was a goal to discuss the pros and cons of citizen science, its many applications, and where they personally saw the future of NPS work with citizen science going. Three out of five

individuals who were interviewed regarding NPS interactions with citizen science were from the Biologic Resources Division, one individual was with Inventory and Monitoring, and one who works closely with Research Learning Centers. All interviewees expressed interest in sharing personal opinions on citizen science work and will continue to work on citizen science side-projects with national parks.

Further Analysis of Results

Further analyses of data are required to paint a full image of the information collected. I will look at the values of data in both the iNaturalist dataset and of the survey dataset and have an introductory discussion of their significance.

iNaturalist

To further analyze the data collected through iNaturalist, it's important to take a closer look at more subtle qualities of the data.

Temporal Qualities of Observations

It is important to note that data collection and general observation frequency has accelerated over time, as displayed in Figure 9. This can be largely credited to the fact that iNaturalist has become more popular as a platform, and as people use it more widely as a pastime to be curious about the outdoors and their surroundings.

The growing popularity of the platform, as it will be referenced later in implications, ensures its stability and guarantees funding opportunities going into the future.

As will be discussed more thoroughly in the discussion, the introduction of a thorough notification system to iNaturalist, specifically to the mobile application, will undoubtedly be required for identifiers on the platform to keep up with the accelerating pace of observations.

Geographic Distribution of Information in Parks

Certain parks and units within the NPS are much more popular for invasive species observations on iNaturalist. Notably, Golden Gate National Recreation Area (GGNRA) in the

Bay Area had by far the most observations of any park. Out of the 11,547 data point set, over 10% of the invasive species data points fall within the boundaries of GGNRA. Although GGNRA has many, many observations, there are dozens of parks without any observations whatsoever, normally those in entirely urban settings, such as the numerous parks in Manhattan, New York City, or in desolate remote locations, such as Gates of the Arctic National Park north of the Arctic Circle in Alaska. This is not to say there are no observations in those parks altogether; it just means there is no targeted invasive vegetation in those parks.

California, as a state, similarly leads for most observations of invasive species in a state. Delaware, who had no national parks until First State National Historic Site was established in 2012, has no observations.

Most observations that occur in parks happen along infrastructure such as roads, trails, and visitor centers (Figure 7); it should be noted that this can cause limitations for tracking invasive vegetation with long-range seed dispersal. Since many pathways for invasion occur near roadways, trails, and other man-made infrastructure, it may be more useful to understand that many observations happen near human development.

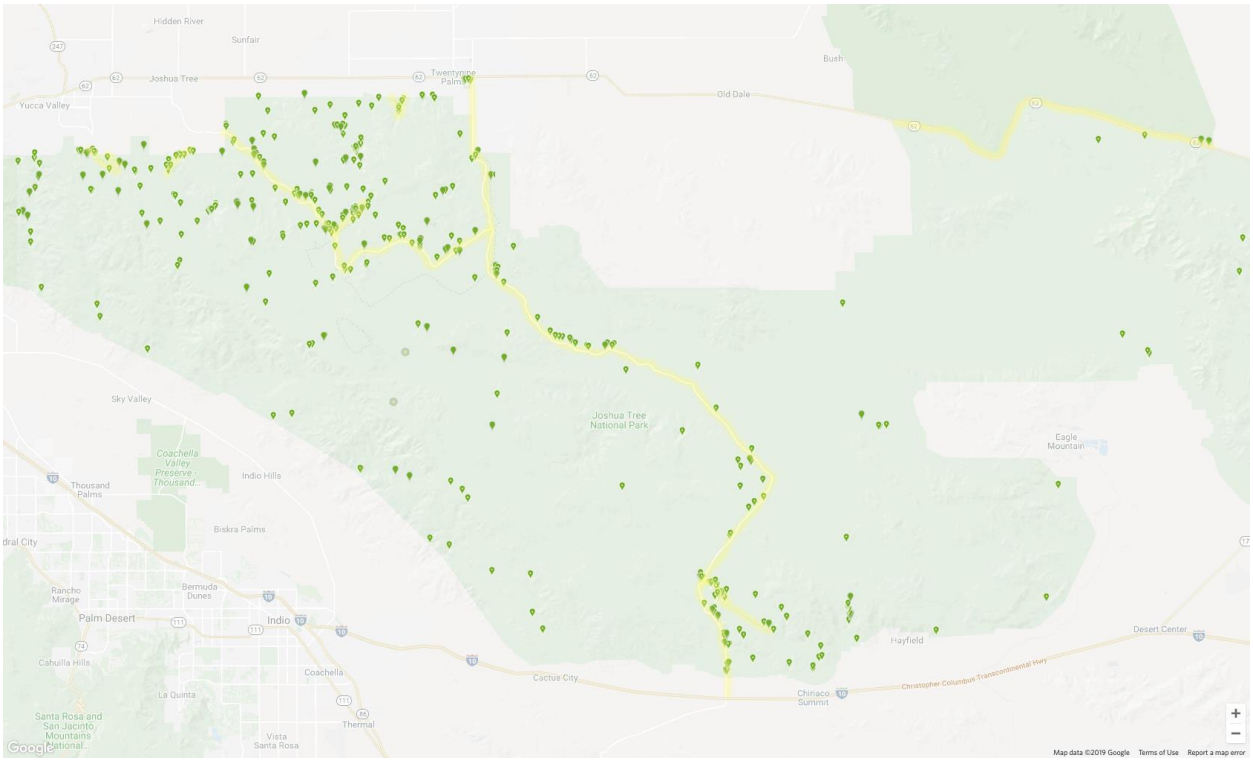


Figure 7: Map of iNaturalist observations within Joshua Tree National Park (JOTR), with major corridors highlighted in yellow. There is a notable amount of backcountry invasive species observations in JOTR, because of a park outreach effort that encourages use of iNaturalist to make observations.

"Research Grade"

iNaturalist determines the validity and value of an observation by assessing its "research grade" worthiness. An observation can attain a research grade status through taxonomic identifications and confirmations that reinforce an initial identification. In the results of the iNaturalist project, 79.8% (9,293) of the observations are indicated research grade. This means that 79.8% of the observations have been double-checked by the online community of amateur scientists and taxonomists. For an observation to be verified, a photo attached to the observation

must demonstrate qualities of a specimen, whether that is its anatomy or setting, that makes the species unique.

Surveys

Responses from the survey indicated that that most applications of citizen science were seen as valuable from the NPS perspective, whether it was educational applications, relationship-building applications, or NPS mission-satisfying applications. Respondents displayed largely favorable views of citizen science as a tool to satisfy the needs of the NPS, but there is one large concern when looking over the collected information: why can't government orgaizations use citizen-collected information to make logical land management decisions? One way to begin investigating this is by running logistic regressions that analyze the relationship between land management decision-making and other utilities of citizen science.

As all general responses to the survey formed positive, reinforcing relationships on citizen science utility, there was significance in each regression run against land management data utility. The relationship with the highest correlation and therefore significance was the regression run between the land management utility of citizen science and the ability of citizen science to satisfy the goals and mission of the NPS.

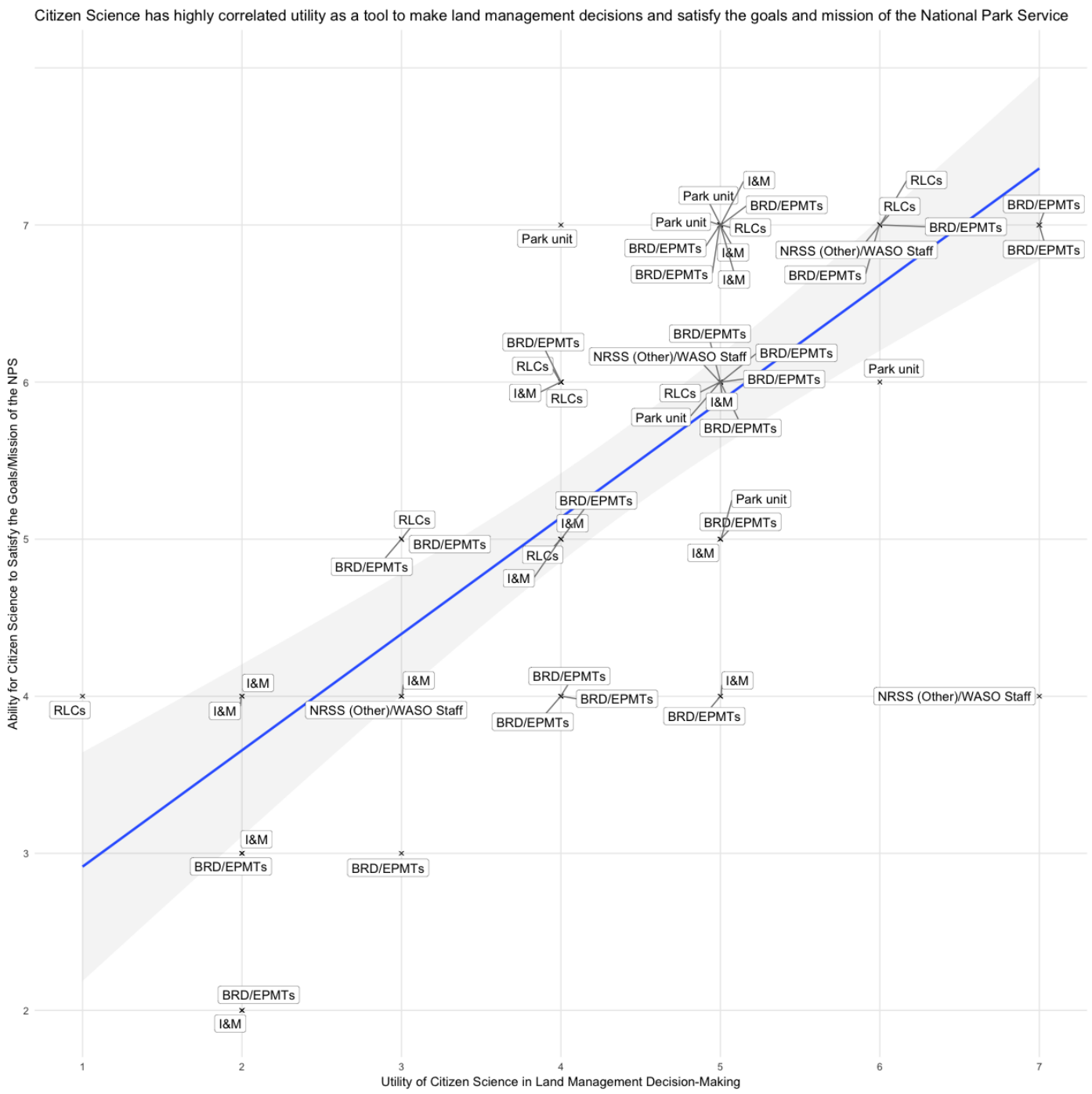


Figure 8: This logistic regression between the "In your opinion, how much usable land management data does citizen science provide?" question and the "In your opinion, how valuable is citizen science as a tool to satisfy the goals/mission of the NPS?" has an R^2 value of 0.499 and a p-value of 7.273^{-10}. Responses from their respective organization (Refer to organizational

flowchart and acronym glossary) within the NPS are plotted at their real response locations. This correlation signifies the close relationship between relationship between citizen science's land management utility and citizen science's ability to satisfy the goals and mission of the NPS.

Discussion

The future of Citizen Science in the NPS is secure, considering that there is large support and many ongoing upstart citizen science programs that range in size from a few participants' to many participants' engagement. The real question I want to answer is what's next for citizen science in the national parks? How can the government build off of what programs already exist?

iNaturalist

Clearly, there is plentiful data among parks that can create actionable plans to manage invasive species by using an EDRR discipline. With many, many data points that can serve as a platform for actionable change, it's important to examine what else stands in the way, internal to the NPS or external.

Using data in a timely manner

In the process of creating the dataset in iNaturalist and looking through and posting that data, I have created a few essential questions:

- How can government agencies use information collected when accounting for the period of data collection and processing?

I found in my work that it may take a significant amount of time to 1) receive adequately vetted information from a program like iNaturalist and 2) take necessary information from those applications and funnel them through invasive species reporting systems that are accepted by the NPS. It may be necessary to implement a collaborative streamlined reporting system connecting the NPS and iNaturalist.

- How likely are land managers to take action on behalf of reported invasive species?

Notable comments from interviews alluded to developing a program, providing as many resources as possible, making it easy and convenient to use, and then nobody using the data collected to assist with land management decisions and actions. I feel that among a community of land managers, oftentimes-old practices are preferential, as they are perceived as more efficient.

- How long does it take invasive species management groups (such as EPMTs) to take action on behalf of information that has been collected?

EPMTs are an excellent example of an effective EDRR program in the National Parks. That being so, EPMTs still have difficulties addressing invasive species concerns on NPS lands in a timely manner, sometimes taking years to respond to an individual concern within an NPS unit. This can arise from a few logistic coal difficulties, from travel distance to a site or park to permitting herbicide use. That doesn't mean that EPMTs haven't shown initiative to act quickly, or to embrace new methods. Former leader of the Southwest EPMT, Steve Buckley, began his own iNaturalist account and began observing invasive species and parks that he traveled to while executing treatments on invasive vegetation. EPMTs are given unique opportunities to develop methods that work best for their corresponding regions and capacities. As a result, it is entirely possible that an EPMT would embrace iNaturalist as a system for early detection.

The popularity of the platform

An undoubtedly true feature of iNaturalist is its continuous growth. With a user base of over a million, iNaturalist receives more and more observations over time.

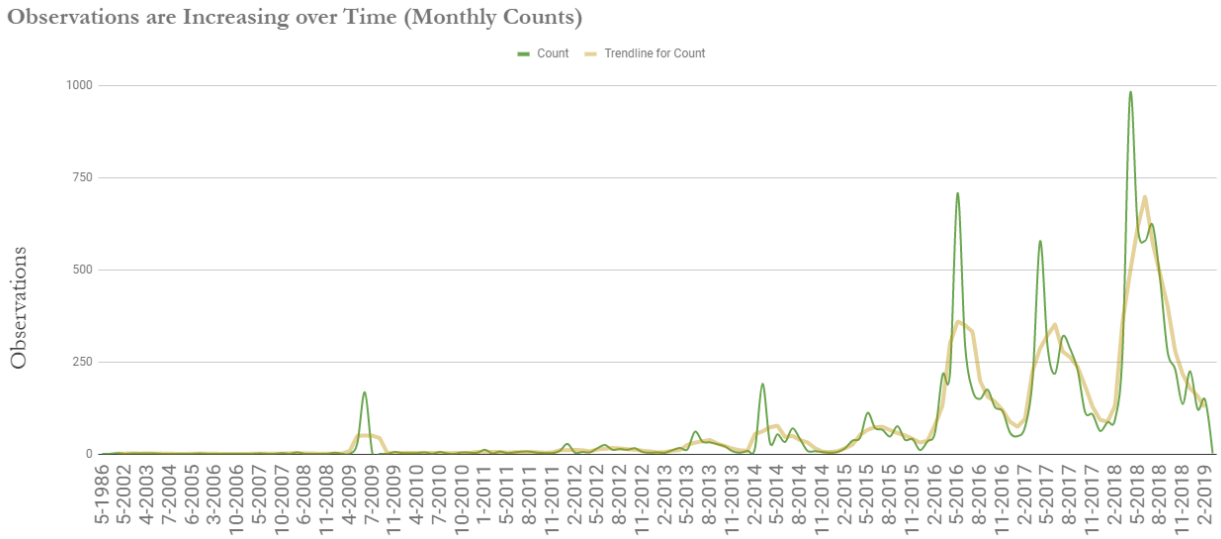


Figure 9: In this graphic, we review monthly counts of observations in our nation-wide project on the green line, and review a general trend line of observations in our nation-wide project in yellow. Since the NPS 2016 Centennial BioBlitz (May 2016), observations within the NPS have seen continuous growth. As iNaturalist grows exponentially, more and more observations will come in about invasive species across the NPS, many of those observations will have significant credibility and therefore actionability. By discovering pathways to make these observations actionable, the NPS can strengthen its approach to managing invasive species on its land.

Bureaucratic hurdles

A few notable bureaucratic hurdles stand in the way of easily producing a system-wide invasive species monitoring and management program. These are not new concerns, yet they were repeatedly brought to attention during the interview stage of data collection.

The Paperwork Reduction Act (PRA) restricts the federal government from holding any personal or traceable information of private citizens for non-safety concerns. Since iNaturalist is a platform that utilizes data collections, usernames, geographic locations, and more potentially

identifying information, iNaturalist and the NPS had to enter a unique task agreement to work together in advance of the 2016 Centennial BioBlitz. This task agreement to find very strict rules for how iNaturalist could be used for NPS purposes, and presents multiple challenges and questions when planning or implementing a citizen science-based invasive species monitoring and management program. A new plan for collaboration between the NPS and iNaturalist would have to go through the Office of Management and Budget (OMB), and would have to offer brought bar brush solutions and uses for iNaturalist that can be described through specific enough language to make the agreement of use to park administrators.

Another issue that was repeatedly brought to face was how much labor would be required to properly vet and process data that was collected through citizen science efforts. A human workforce capacity to access, manage, and distribute data among peers would be required to properly manage a program that monitors invasive species within national parks.

Relaying information for actionable directives

As mentioned before, by establishing a human workforce capacity to oversee citizen science-based invasive species monitoring and management program within the NPS, many other tasks could be performed that are critical to making sure the program would function. Different actions that could be undertaken could include sending information to parks, nonprofits, EPMTs, and the like; providing identification services for the project, double checking the identifications that come in from throughout the country; providing logistical support to invasive management groups throughout the parks, performing administrative tasks and planning travel and logistical procedures.

By establishing aforementioned capacity, the NPS would be providing early detection and expecting a rapid response from pre-existing structures within the service, whether that is local land managers or larger teams such as the EPMTs. Realistically speaking, rapid responses are less likely, rather timely responses would happen by utilizing existing capacities within the NPS to manage invasive species.

Formatting of projects to include treatment lists and priority watch lists

In order to keep projects maintained properly, species lists on the iNaturalist projects should be updated regularly to include any arising invasive threats or potential arising threats. As it will be stated in the limitations, this can be a costly process in both labor and energy. This process of updating land management databases can be burdensome on parks and land managers who already have a lot to do. By establishing a capacity, as mentioned before, some of the work in maintaining these databases could be offloaded.

Survey Responses

The significance of the regression between respondents who indicated that citizen science served the mission of the NPS respondents finding value in land management applications of citizen science indicated that among NPS staff, citizen science's ability to satisfy the goals and mission of the agency is heavily correlated with its ability to provide data that can inform land management decision-making. Between the other factors that gave citizen science a valuation, land management data utility had no comparison. Results generally indicated that there was no significant relationship between the educational value or relationship building value that citizen science provides and its land management utility.

Among the impression responses that were regressed with the "In your opinion, how valuable is citizen science as a tool to satisfy the goals/mission of the NPS?" response, land management data utility had the highest correlation. This suggests that, although the educational value and relationship-building value of citizen science is important, ultimately land management utility stands out as the strongest factor that can satisfy the goals and mission of the NPS. Moreover, this is alarming, because citizen science did not scale up nearly as well as the other variables on whether it had land management decision-making utility. General impressions here would indicate that citizen science might be a weak tool to address the core goals and mission of the agency because of the impression that citizen science lacks the ability to provide usable land management information.

In addition, regressions were run scaling participation rates (i.e. numbers of participants) at events with the impression variables, and no significant correlations were found.

Interviews

Interviews provided much needed additional input on the citizen science process in national parks. The interviews provided both optimistic and pessimistic outlooks on how the future of citizen science looked in the NPS. In general, like the survey results, reviews of citizen science were favorable, but there seemed to be a loss for words at times for potential applications of the information that was being collected. Sample interview questions that formed a platform for discussion are outlined in Appendix A.

Applicability of the true data set that was collected from iNaturalist

Over half of the survey respondents indicated that data collected from citizen science is applicable to land management decision making. The large iNaturalist data set indicates that there is already an excess of passively collected information on species in national parks, without any encouragement or stimulation to collect that information on behalf of the NPS.

Impressions about proper vetting processes in citizen science projects

During interviews, the validity and vetting methods involved in the citizen science process were called into question multiple times. Although platforms such as iNaturalist have features built in to account for proper vetting and identification procedures, it seems that many who have interacted with citizen science in the past have an impression that for some reason data are not validated properly or by professionals in the field, therefore it is difficult to assess the true worth of collected citizen science data to create actionable plans.

This discrepancy that was described in interviews could largely explain reluctance to using citizen science information to make land management decisions in the survey responses.

Applying iNaturalist observations to on-the-ground invasive species management

Through our data, it is obvious that iNaturalist, among other citizen science platforms and methods, could potentially provide a useful system to supplement the NPS in early detection and rapid response of invasive species.

Limitations

iNaturalist

iNaturalist as a platform has a few notable shortcomings, that have not yet been described in academia. Among those who use and interact with the data products of the platform, there is a common list of concerns regarding the altruistic methods the platform uses to collect, verify, and assemble its data.

Since a system of community review by experts and amateur scientists generates identifications, it is not certain that all observations and documentations of species presence can be wholly accurate. In addition, machine learning is heavily used on the platform as a method to catalyze user species identifications. Despite the technology showing a lot of promise, machine learning has been shown to make some mistakes (Van Horn et al., 2017).

Oftentimes, observers use iNaturalist as a platform to upload historic photos and observations they made years ago. Approximations are made when users decide to place their observation on a map, and as a result, there may be many concerns on the geolocation accuracy of observations. In addition, users mostly use mobile devices to observe, although observations may not reflect the geolocation precision of their specific device. To ensure geolocation accuracy, there must be a requirement for proper vetting on behalf of the NPS or other land management agencies to ensure that geolocation accuracy is, in fact, precise enough to make properly informed decisions. Fortunately, iNaturalist has a field in its data exports that include geolocation accuracy (that is, if there is a mobile device attached to an observation).

Amateur scientists can often make procedural mistakes in observations, or collect difficult-to-identify photographs that make reinforcing identifications nearly impossible. In addition, community identifications of specimens can often be inaccurate, as amateur scientists

may not have enough familiarity with the discipline of biology that they are identifying. Inaccurate identifications can lead to improper on-the-ground actions, if data are not vetted properly in an EDRR system. Fortunately, iNaturalist has been improving its front-end user interface identification system, where identifiers can see specimen examples and descriptions to make sure their identifications are appropriate. Identifiers are also generally encouraged to organize identifications into a higher taxonomic group, if they are uncertain of species-level identification.

Furthermore, iNaturalist presents an issue when you consider that a "research-grade" observation only requires two concurrent identifications. Two concurrent identifications by amateur scientists can lead to a vastly improper identification.

iNaturalist notably experiences a "learning curve" issue as well, where a new user on mobile (the most common introduction platform) can be intimidated by a complex user interface and limited functionality when compared to the website. The user interface does not supply much in regards to looks, as the screen is not filled with as many visual elements as other applications that can draw a new user's attention away. Visual improvements to the mobile application that improve functionality and ease-of-use are a likely way to generate a larger community on iNaturalist.

At the NPS, it is important to consider that there are not sufficient resources to maintain, develop, and distribute an invasive species management program. There is not ample national-level capacity to pursue invasive species management through partnerships yet, although a pathway can be opened up to enable funding and collaboration.

The iNaturalist projects have a few inherent limitations as well. Thirty-one separate projects are substantially difficult to maintain, as compared to one national coordinating project.

Maintaining 32 separate projects involves challenges such as keeping species lists responsive to change, updating imperfections, continuously providing correspondence and resources to park administrators that request information, conducting outreach to publicize an efficient, new program that the public can help with, and creating other resources for internal and external organizations to discuss methods and potential improvements. In addition, the manager of all these projects must keep graphical aesthetics up-to-date, as features on iNaturalist would change, upper management would have different requests of the project, and general improvements must be applied. This maintenance must occur in all 32 separate projects consistently, and would be a huge capacity burden on a stretched-thin workforce.

Surveys

One notable aspect of our survey is that most respondents to the survey belonged to the Washington D.C. office, specifically the Natural Resource Stewardship and Science Directorate. As a result, the survey performs a much more functional role as an "administrative take" on natural resource functionality and management. It reflects more upon management's desires and wishes of park units to conduct citizen science, rather than a de facto park-based consensus on the use and utility of citizen science.

An improvement to the study would include broader distribution to parks and frontline land managers within the NPS, so that they could respond to the survey and have their thoughts heard on citizen science projects.

In the same vein as distribution, it should be noted that the survey was time sensitive, because of the government shutdown that ran from December 2018 until late January 2019, when data collection should have been pursued. If there had been ample time to collect

information and receive permission for broad distribution of the survey, results may have returned with more statistical backing. Because of the government shutdown, it should be considered that this survey and data collection period was severely time constrained.

Another factor to consider in the limitations of our survey is that over 70% of our respondents had previously participated in the citizen science event, likely skewing our results in preference of citizen science. By only having people who have worked with citizen science, it would be difficult to say that their willing action to engage in citizen science served their dislike for it. It should be noted however, that of all respondents who had not participated in citizen science, none of them said that they would not participate in citizen science. There was unanimous interest in engaging with citizen science among those who had not.

Conclusions

Results indicated a few essential findings:

- NPS leadership continues to support citizen science as a tool to satisfy multiple needs of the organization.
- NPS leadership largely affirms the utility of citizen science in multiple capacities.
- There is unanimous interest in using citizen science among NPS survey participants who have not used or participated in it before ($n_{not\ participated}=16$).
- Although all relationships show that citizen science has more utility than not in any capacity, there is a significant relationship amongst models indicating that there is an impression that citizen science provides less utility to help make land management decisions and actionable plans related to land management.
- There is a wealth of verifiable data that has been collected by citizen scientists passively over time, and the rate of this incoming data are increasing.
- With the development of proper verification and validation methodologies, these data can have the potential to impact invasive species tracking, invasive species management, and the development of tools and procedures to make citizen science-gathered information actionable by frontline land managers.
- A few obstacles, bureaucratic and logistical, stand in the way of implementing actual change that will utilize citizen science, as policy can bar activities that use citizen-collected information, and the Terms of Service of open source projects like iNaturalist can cause legal conflicts for federal workers.

Results demonstrate that there is considerable citizen science valuation from the NPS perspective, and that passive, un-encouraged observations of invasive vascular plants number more than 10,000 across all units of the national parks, giving merit to citizen science as a powerful way to collect significant amounts of information. With proper verification and validation methodologies, these data may be a cost-effective means to help respond to invasive species and augment existing early detection and rapid response practices, while simultaneously encouraging public education and engagement with national parks.

Implications

There are many ways to continue the work that I have started here, collecting more information being one of them. Beyond that, I have some recommendations to accelerate technological development and stakeholder engagement.

- The NPS can create a program to formally establish EDRR invasive species control among its units. This system could involve a few parks as a pilot project, and focus heavily on outreach and capacity building to respond to quickly to arising invasive species concerns. Success at a smaller scale can initialize more widespread support and interest in such programs.
- As an alternative to establishing a full-fledged program, the NPS can organize smaller events to formally indoctrinate or encourage data gathering on invasive species within parks. Events are more likely to require less long-term capacity on behalf of parks, and can immediately be followed up by the response to arising invasive threats.
- The NPS can also utilize its close connections and evolving task agreements to build new tools in iNaturalist that will aid identification and reporting processes, enabling land managers to assist the data collection process and readily access information.
- The NPS can support efforts to establish minimal requirements to verify and validate citizen science-collected data, such that it would be considered useful in land management decision-making and actions.
- Furthermore, the NPS needs to consistently pursue outreach and engagement through other channels to notify the public about invasive threats, programs that monitor and control invasive species, and actionable opportunities for citizen engagement.

- The NPS should also continue building relationships with nonprofits to encourage citizen science data-gathering and information sharing, especially in areas of concern where the parks service may not be readily able to respond due to bureaucratic concerns (i.e. funding, supplying capacity/labor, and creating interpretive materials).

Figure 10: In our survey, I also asked respondents to reflect upon what can be improved in regards to citizen science in the national parks. This word cloud was produced reflecting those comments. Some individuals reflected upon the logistical challenges they faced in accessing data, gaining turnout, accessing outreach materials, and overcoming technical and bureaucratic obstacles with organizing citizen science events. Another common theme reflected upon how much effort it took to organize and execute an event.

Appendix A: Reference content

Acronym Glossary

Acronym	Expanded Form
BRD	Biological Resources Division
DENA	Denali National Park
DOI	Department of the Interior
EDDMapS	Early Detection Distribution and Mapping System
EPMT	Exotic Plant Management Team
GGNRA	Golden Gate National Recreation Area
GLAC	Glacier National Park
IPP	Invasive Plant Program
IRMA	Integrated Resource Management Applications
I&M	Inventory and Monitoring Division
IS	invasive species
IUCN	International Union for the Conservation of Nature
JOTR	Joshua Tree National Park
LRAB	Landscape Restoration and Adaptation Branch
NISIMS	National Invasive Species Information and Management System
NPS	National Park Service
NRSS	Natural Resource Stewardship and Science Directorate
OMB	Office of Management and Budget
PRA	Paperwork Reduction Act
RLC	Research Learning Center
USFS	United States Forest Service

Survey Questions

- Which organization of the National Park Service do you belong to?
- How long have you served within the National Park Service?
- How long have you served with your current organization?
- Have you collaborated with citizen science efforts before?

- If yes
    - When did you most recently organize or host a citizen science event? (Multiple choice)
    - Approximately how many participants and citizen scientists joined you? (Manual entry box)
    - What were the goals of the citizen science event?
        - Invasive species management
        - Citizen engagement/awareness
        - Finding new species to a park
        - General inventorying
        - Massive data gathering for research
        - Community collaborations
        - Other (manual entry field)
    - Have you used information collected from your citizen science efforts?
    - How have you used information collected from citizen scientists?
- If no
    - Would you be willing to work on a citizen science related project? (This does not put you on a mailing list or database)
    - Do you feel there are sufficient resources offered to help you organize a citizen science/BioBlitz event?

- In your opinion, how much educational value does citizen science provide to visitors and staff? (1-7)

- In your opinion, does citizen science create a positive relationship between visitors, park staff, and researchers? (1-7)
- In your opinion, how much usable land management data does citizen science provide? (1-7)
- In your opinion, how valuable is citizen science overall to the needs of the NPS? (1-7)
- In your opinion, what are the best goals for the use of citizen science within parks?
    - Invasive species identification and management
    - Citizen engagement/awareness
    - Finding new species to a park
    - General inventorying
    - Massive data gathering for research
    - Community collaborations
    - Other (manual entry field)
- Do you feel that the parks could utilize citizen science in a better way? If so, briefly describe how. (manual entry field)

Standard Interview Questions

- How do you think you can use iNaturalist?
- What is needed to help you work with iNaturalist?
    - Development of a project, custom fields, etc.?
- Do you feel iNaturalist is an effective tool for public engagement?
- Do you feel that iNaturalist has applications for resource management in the NPS?

- How can organizations within the NPS collaborate across branches and divisions to use iNaturalist to collect and organize data, and eventually take action?
- What challenges have you faced while working with iNaturalist in the past?
    - Do you have any recommendations for solutions?
- What resources can iNaturalist provide for the National Park Service?

Appendix B: Additional Images, Figures, and Graphs

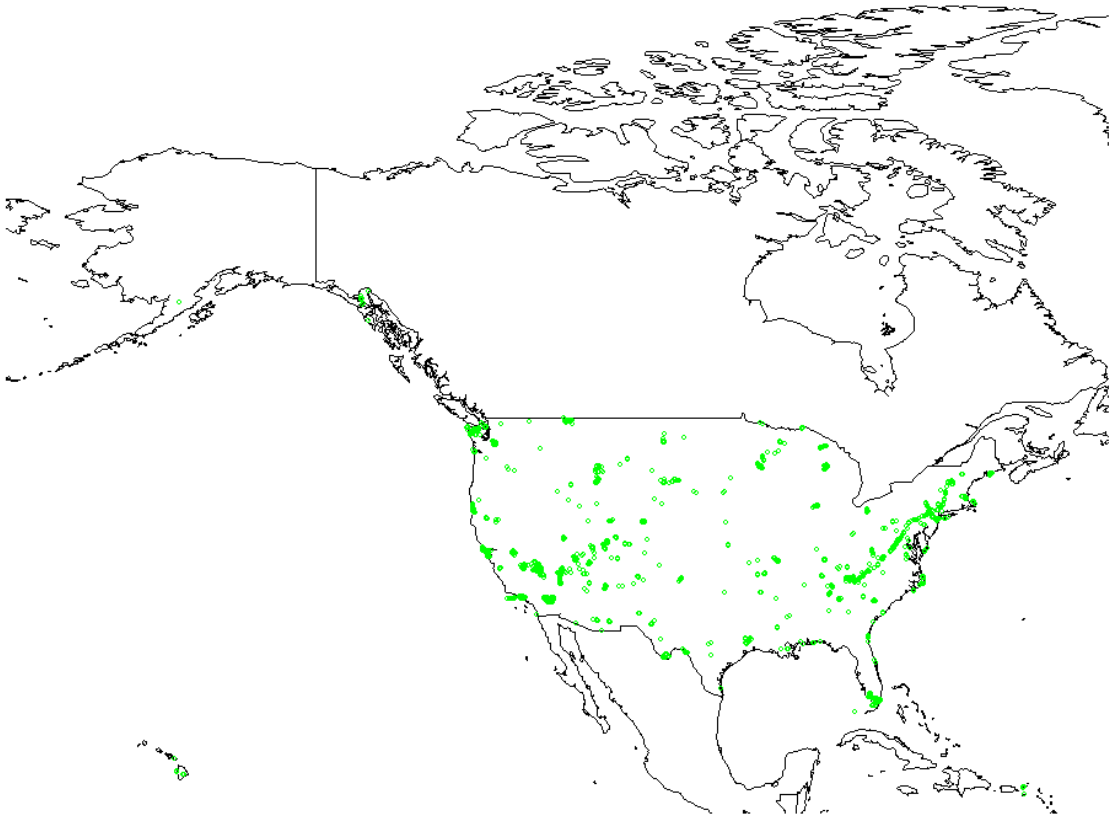


Figure 11: Geographic distribution of observations in the United States, compiled in R. This view tends to cluster observations majorly, as each miniscule green dot signifies a single observation of over 11,500 observations.

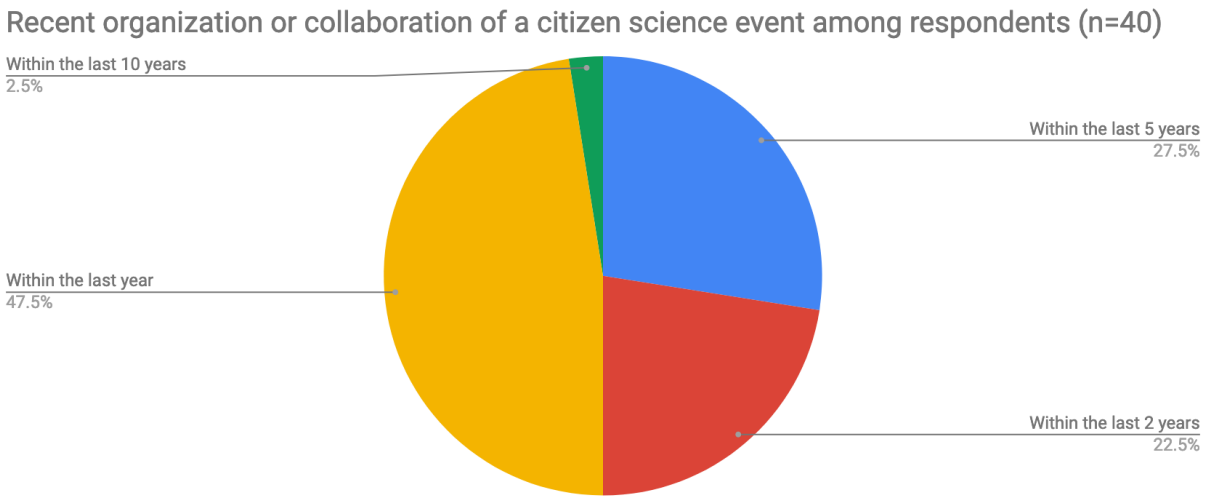


Figure 12: Time period in which respondents were last involved in a citizen science event in parks.

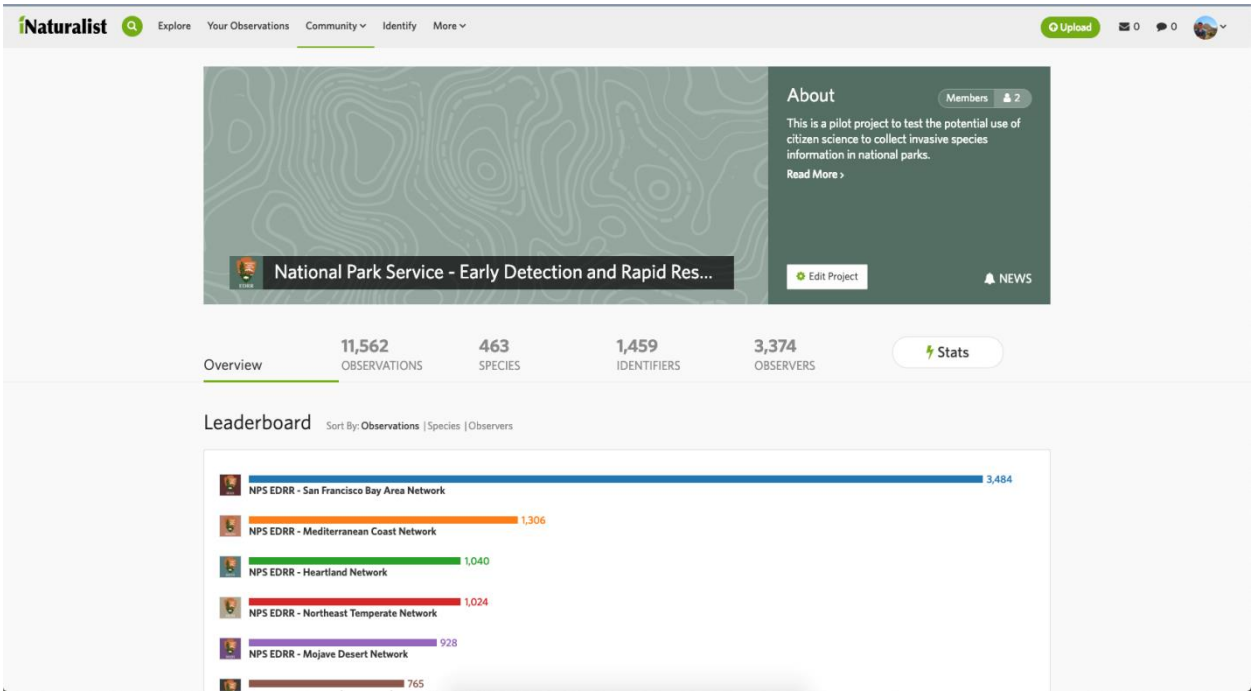


Figure 13: Landing page view of the nation-wide iNaturalist EDRR umbrella project.

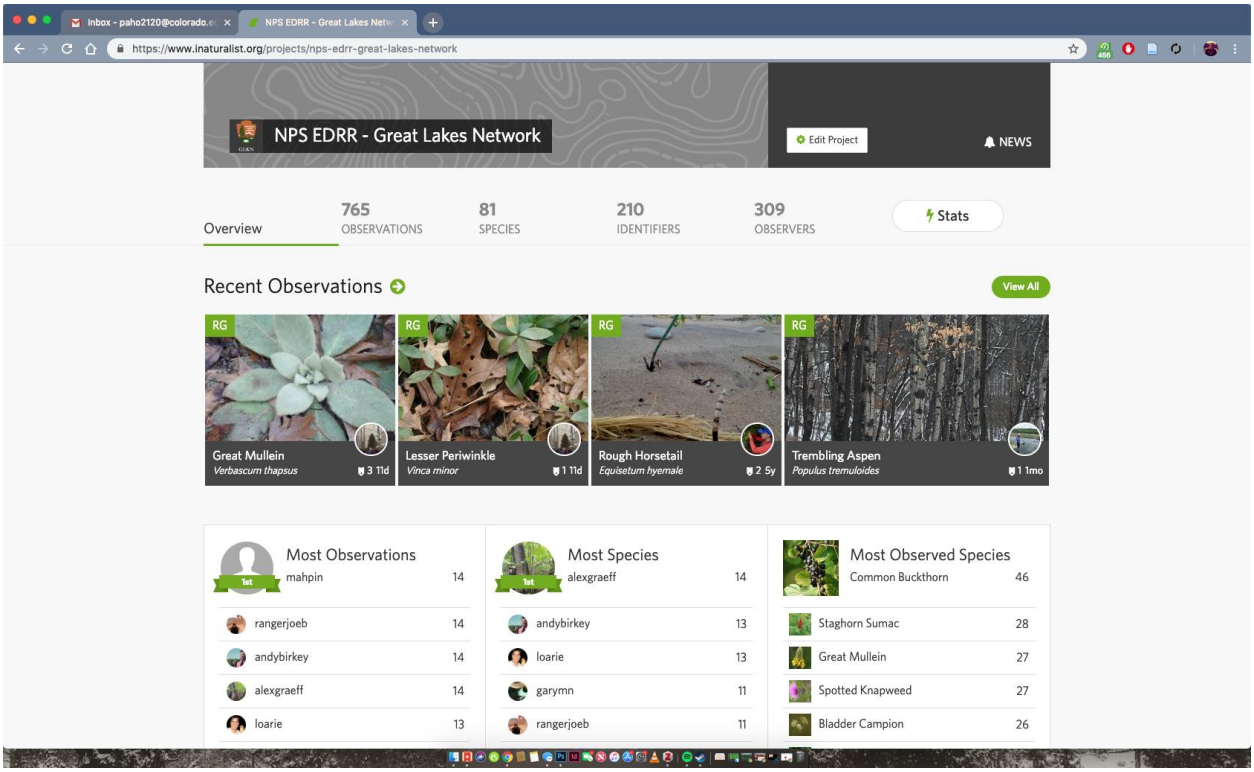


Figure 14: Landing page for one of the 32 regional projects in the NPS EDRR nation-wide project.

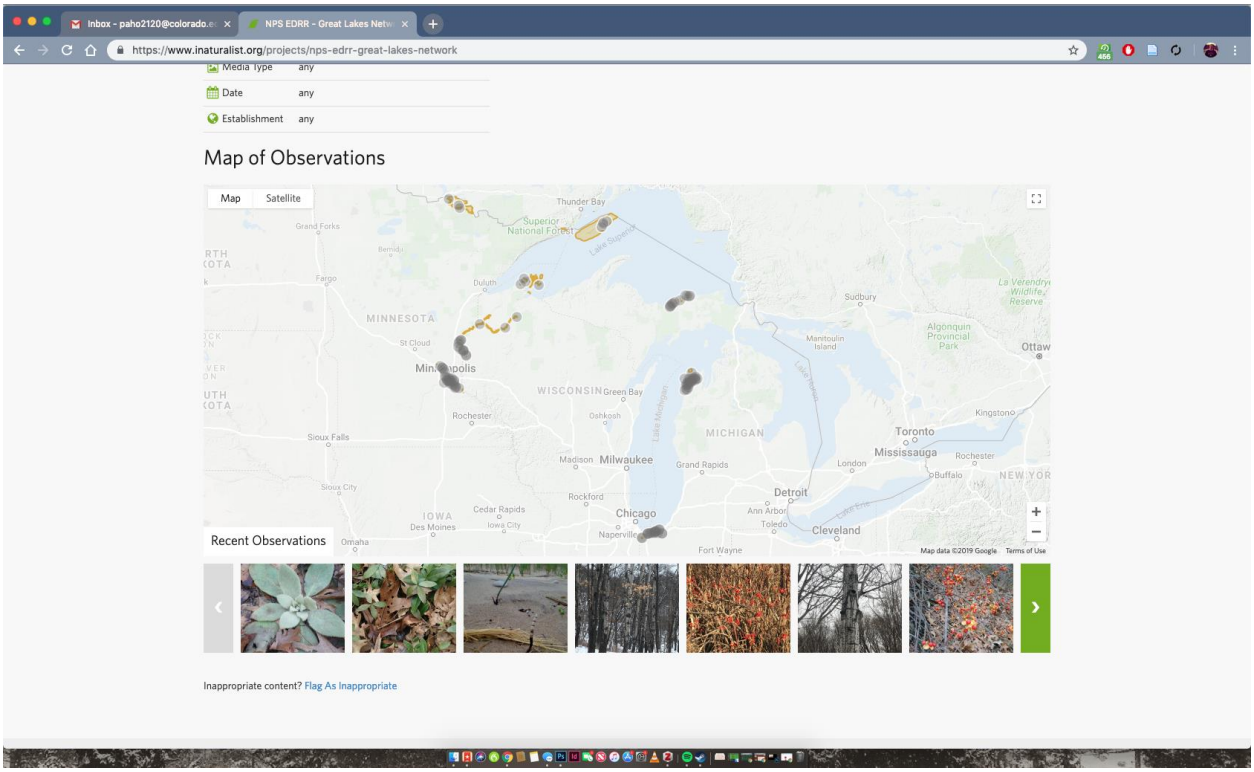


Figure 15: Map of the Great Lakes EDRR collection project, including parks from the Great Lakes Inventory and Monitoring Network. Orange outline indicate geographic polygons where observation occur within, and dots indicate locations of observations that match the parameters of the project, including custom NPS treated species lists.

Bibliography

Abella, Scott R. "Effectiveness of Exotic Plant Treatments on National Park Service Lands in the United States." *Invasive Plant Science and Management*, vol. 7, no. 1, Mar. 2014, pp. 147–63. *Cambridge Core*, doi:10.1614/IPSM-D-13-00058.1.

"About · INaturalist.Org." *INaturalist.Org*, https://www.inaturalist.org/pages/about. Accessed 7 Mar. 2019.

Allen, Julia A., et al. "Non-Native Plant Invasions of United States National Parks." *Biological Invasions*, vol. 11, no. 10, Dec. 2009, pp. 2195–207. *Springer Link*, doi:10.1007/s10530-008-9376-1.

"Automating the Use of Citizen Scientists' Biodiversity Surveys in INaturalist to Facilitate Early Detection of Species' Responses to Climate Change." *Community for Data Integration - MyUSGS Confluence*, https://www.usgs.gov/centers/cdi/science/automating-use-citizen-scientists-biodiversity-surveys-inaturalist-facilitate?qt-science_center_objects=0#qt-science_center_objects. Accessed 6 Mar. 2019.

Beissinger, Steven R., et al. *Science, Conservation, and National Parks*. University of Chicago Press, 2017.

BenDor, Todd K., and Sara S. Metcalf. "The Spatial Dynamics of Invasive Species Spread." *System Dynamics Review*, vol. 22, no. 1, Mar. 2006, pp. 27–50. *Wiley Online Library*, doi:10.1002/sdr.328.

Biological Resources Division (U.S. National Park Service). https://www.nps.gov/orgs/1103/index.htm. Accessed 4 Mar. 2019.

Bonney, Rick, et al. “Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy.” *BioScience*, vol. 59, no. 11, Dec. 2009, pp. 977–84. *academic-oup-com.colorado.idm.oclc.org*, doi:10.1525/bio.2009.59.11.9.

Bradley, Bethany A., et al. “Invasive Species Risk Assessments Need More Consistent Spatial Abundance Data.” *Ecosphere*, vol. 9, no. 7, July 2018, p. e02302. *Wiley Online Library*, doi:10.1002/ecs2.2302.

Budde, Peter, and Simon Kingston. “Data Management for National Park Service-National Geographic Society Bioblitzes.” *Park Science*, vol. 31, no. 1, Nov. 2014, https://www.nps.gov/articles/-parkscience-v31-1_kingston_budde-htm.htm.

Citizen Science (U.S. National Park Service). https://www.nps.gov/subjects/citizenscience/index.htm. Accessed 14 Mar. 2019.

Cohn, Jeffrey P. “Citizen Science: Can Volunteers Do Real Research?” *BioScience*, vol. 58, no. 3, Mar. 2008, pp. 192–97. *academic.oup.com*, doi:10.1641/B580303.

Crall, Alycia, et al. “The Impacts of an Invasive Species Citizen Science Training Program on Participant Attitudes, Behavior, and Science Literacy.” *Public Understanding of Science (Bristol, England)*, vol. 22, Apr. 2012. *ResearchGate*, doi:10.1177/0963662511434894.

Crall, Alycia W., Gregory J. Newman, Thomas J. Stohlgren, et al. “Assessing Citizen Science Data Quality: An Invasive Species Case Study.” *Conservation Letters*, vol. 4, no. 6, Dec. 2011, pp. 433–42. *Wiley Online Library*, doi:10.1111/j.1755-263X.2011.00196.x.

Crall, Alycia W., Gregory J. Newman, Catherine S. Jarnevich, et al. “Improving and Integrating Data on Invasive Species Collected by Citizen Scientists.” *Biological Invasions; Dordrecht*, vol. 12, no. 10, Oct. 2010, pp. 3419–28. *ProQuest*, doi:http://dx.doi.org.colorado.idm.oclc.org/10.1007/s10530-010-9740-9.

Cronje, Ruth, et al. “Does Participation in Citizen Science Improve Scientific Literacy? A Study to Compare Assessment Methods.” *Applied Environmental Education & Communication*, vol. 10, no. 3, July 2011, pp. 135–45. *Taylor and Francis+NEJM*, doi:10.1080/1533015X.2011.603611.

Delaney, David G., et al. “Marine Invasive Species: Validation of Citizen Science and Implications for National Monitoring Networks.” *Biological Invasions*, vol. 10, no. 1, Jan. 2008, pp. 117–28. *Springer Link*, doi:10.1007/s10530-007-9114-0.

Diamond, J. “‘Normal’ Extinctions of Isolated Populations.” *Extinctions*, edited by MH Nitecki, Chicago University Press, 1984, pp. 191–246.

Dickinson, Janis L., et al. “The Current State of Citizen Science as a Tool for Ecological Research and Public Engagement.” *Frontiers in Ecology and the Environment*, vol. 10, no. 6, Aug. 2012, pp. 291–97. *Wiley Online Library*, doi:10.1890/110236.

Executive Order 13751 - Safeguarding the Nation from the Impacts of Invasive Species | National Invasive Species Information Center | USDA. https://www.invasivespeciesinfo.gov/executive-order-13751. Accessed 17 Mar. 2019.

Freitag, Amy, et al. “Strategies Employed by Citizen Science Programs to Increase the Credibility of Their Data.” *Citizen Science: Theory and Practice*, vol. 1, no. 1, May 2016, p. 2. census, *theoryandpractice.citizenscienceassociation.org*, doi:10.5334/cstp.6.

Gallo, Travis, and Damon Waitt. “Creating a Successful Citizen Science Model to Detect and Report Invasive Species.” *BioScience*, vol. 61, no. 6, June 2011, pp. 459–65. *academic-oup-com.colorado.idm.oclc.org*, doi:10.1525/bio.2011.61.6.8.

Graham, Eric A., et al. “Using Mobile Phones to Engage Citizen Scientists in Research.” *Eos, Transactions American Geophysical Union*, vol. 92, no. 38, Sept. 2011, pp. 313–15. *Wiley Online Library*, doi:10.1029/2011EO380002.

Guiaşu, Radu Cornel. *Non-Native Species and Their Role in the Environment*. Brill, 2016. *booksandjournals.brillonline.com*, doi:10.1163/9789047426134.

Haklay, Muki. "Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation." *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*, edited by Daniel Sui et al., Springer Netherlands, 2013, pp. 105–22. *Springer Link*, doi:10.1007/978-94-007-4587-2_7.

Hellmann, Jessica J., et al. "Five Potential Consequences of Climate Change for Invasive Species." *Conservation Biology*, vol. 22, no. 3, June 2008, pp. 534–43. *Wiley Online Library*, doi:10.1111/j.1523-1739.2008.00951.x.

Jordan, Rebecca C., Amanda E. Sorensen, et al. "Citizen Science and Civic Ecology: Merging Paths to Stewardship." *Journal of Environmental Studies and Sciences*, Sept. 2018. *Springer Link*, doi:10.1007/s13412-018-0521-6.

Jordan, Rebecca C., Wesley R. Brooks, et al. "Evaluating the Performance of Volunteers in Mapping Invasive Plants in Public Conservation Lands." *Environmental Management*, vol. 49, no. 2, Feb. 2012, pp. 425–34. *Springer Link*, doi:10.1007/s00267-011-9789-y.

Kaiser, Brooks A., and Kimberly M. Burnett. "Spatial Economic Analysis of Early Detection and Rapid Response Strategies for an Invasive Species." *Resource and Energy Economics*, vol. 32, no. 4, Nov. 2010, pp. 566–85. *ScienceDirect*, doi:10.1016/j.reseneeco.2010.04.007.

Lewandowski, Eva, and Hannah Specht. "Influence of volunteer and project characteristics on data quality of biological surveys." *Conservation Biology*, vol. 29, no. 3, June 2015, pp. 713–23. *Wiley Online Library*, doi:10.1111/cobi.12481.

Marris, Emma. "Shoot to Kill." *Nature; London*, vol. 438, no. 7066, Nov. 2005, pp. 272–73.

McKinley, Duncan C., et al. "Citizen Science Can Improve Conservation Science, Natural Resource Management, and Environmental Protection." *Biological Conservation*, vol. 208, Apr. 2017, pp. 15–28. *ScienceDirect*, doi:10.1016/j.biocon.2016.05.015.

Minor, Emily S., and Robert H. Gardner. "Landscape Connectivity and Seed Dispersal Characteristics Inform the Best Management Strategy for Exotic Plants." *Ecological Applications*, vol. 21, no. 3, Apr. 2011, pp. 739–49. *Wiley Online Library*, doi:10.1890/10-0321.1.

Natural Resource Stewardship and Science Directorate (U.S. National Park Service). https://www.nps.gov/orgs/1778/index.htm. Accessed 4 Mar. 2019.

Nov, Oded, et al. "Scientists@Home: What Drives the Quantity and Quality of Online Citizen Science Participation?" *PLOS ONE*, vol. 9, no. 4, Apr. 2014, p. e90375. *PLoS Journals*, doi:10.1371/journal.pone.0090375.

---. *Technology-Mediated Citizen Science Participation: A Motivational Model*. 2011, p. 8.

Nugent, Jill. "INaturalist." *Science Scope; Washington*, vol. 41, no. 7, Mar. 2018, pp. 12–13.

Pimentel, David, Lori Lach, et al. "Environmental and Economic Costs of Nonindigenous Species in the United States." *BioScience*, vol. 50, no. 1, Jan. 2000, pp. 53–65. *bioone.org.colorado.idm.oclc.org (Atypon)*, doi:10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2.

Pimentel, David, Rodolfo Zuniga, et al. "Update on the Environmental and Economic Costs Associated with Alien-Invasive Species in the United States." *Ecological Economics*, vol. 52, no. 3, Feb. 2005, pp. 273–88. *ScienceDirect*, doi:10.1016/j.ecolecon.2004.10.002.

Randall, John M., et al. "The Invasive Species Assessment Protocol: A Tool for Creating Regional and National Lists of Invasive Nonnative Plants That Negatively Impact Biodiversity." *Invasive*

Plant Science and Management, vol. 1, no. 1, Jan. 2008, pp. 36–49. *Cambridge Core*, doi:10.1614/IPSM-07-020.1.

Salafsky, Nick, et al. "A Standard Lexicon for Biodiversity Conservation: Unified Classifications of Threats and Actions." *Conservation Biology*, vol. 22, no. 4, Aug. 2008, pp. 897–911. *Wiley Online Library*, doi:10.1111/j.1523-1739.2008.00937.x.

Selleck, Jeff, et al., editors. *Park Science 31-1: BIOLOGICAL DIVERSITY: DISCOVERY, SCIENCE, AND MANAGEMENT*. 1st ed., vol. 31, U.S. Department of the Interior, National Park Service, Natural Resource Stewardship and Science Office of Education and Outreach Lakewood, Colorado, 2014, https://www.nps.gov/subjects/parkscience/upload/ParkScience31-1-SpecialIssue2014_-WCAG2-0.pdf.

Silvertown, Jonathan, et al. "Crowdsourcing the Identification of Organisms: A Case-Study of ISpot." *ZooKeys*, no. 480, Feb. 2015, pp. 125–46. *PubMed Central*, doi:10.3897/zookeys.480.8803.

Simpson, Annie, et al. "Invasive Species Information Networks: Collaboration at Multiple Scales for Prevention, Early Detection, and Rapid Response to Invasive Alien Species." *Biodiversity*, vol. 10, no. 2–3, Sept. 2009, pp. 5–13. *Taylor and Francis+NEJM*, doi:10.1080/14888386.2009.9712839.

Society, National Geographic. *BioBlitz Program*. http://www.nationalgeographic.org/projects/bioblitz/. Accessed 14 Mar. 2019.

Specht, Hannah, and Eva Lewandowski. "Biased Assumptions and Oversimplifications in Evaluations of Citizen Science Data Quality." *The Bulletin of the Ecological Society of America*, vol. 99, no. 2, Apr. 2018, pp. 251–56. *Wiley Online Library*, doi:10.1002/bes2.1388.

Temple, Stanley A. "The Nasty Necessity: Eradicating Exotics." *Conservation Biology*, vol. 4, no. 2, June 1990, pp. 113–15. *Wiley Online Library*, doi:10.1111/j.1523-1739.1990.tb00096.x.

Theobald, E. J., et al. "Global Change and Local Solutions: Tapping the Unrealized Potential of Citizen Science for Biodiversity Research." *Biological Conservation*, vol. 181, Jan. 2015, pp. 236–44. *ScienceDirect*, doi:10.1016/j.biocon.2014.10.021.

Trumbull, Deborah J., et al. "Thinking Scientifically during Participation in a Citizen-Science Project." *Science Education*, vol. 84, no. 2, Mar. 1999, pp. 265–75. *Wiley Online Library*, doi:10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5.

US Department of State. "Invasive Species." *Invasive Species*, https://www.state.gov/e/oes/ocns/opa/marine/invasive/. Accessed 19 Dec. 2018.

US Department of the Interior. "Executive Order 13751." *Executive Order 13751 of December 5, 2016*, 21 Dec. 2016, https://www.doi.gov/invasivespecies/executive-order-13751.

Van Horn, Grant, et al. "The INaturalist Species Classification and Detection Dataset." *ArXiv:1707.06642 [Cs]*, July 2017. *arXiv.org*, http://arxiv.org/abs/1707.06642.

VITOUSEK, PETER M., et al. "INTRODUCED SPECIES: A SIGNIFICANT COMPONENT OF HUMAN-CAUSED GLOBAL CHANGE." *New Zealand Journal of Ecology*, vol. 21, no. 1, 1997, pp. 1–16.

Vuilleumier, S., et al. "Invasion and Eradication of a Competitively Superior Species in Heterogeneous Landscapes." *Ecological Modelling*, vol. 222, no. 3, Feb. 2011, pp. 398–406. *ScienceDirect*, doi:10.1016/j.ecolmodel.2010.09.037.

Wagner, Viktoria, et al. "Herbicide Usage for Invasive Non-Native Plant Management in Wildland Areas of North America." *Journal of Applied Ecology*, vol. 54, no. 1, Feb. 2017, pp. 198–204. *Wiley Online Library*, doi:10.1111/1365-2664.12711.

Westbrooks, Randy G. "New Approaches for Early Detection and Rapid Response to Invasive Plants in the United States." *Weed Technology*, vol. 18, no. sp1, Dec. 2004, pp. 1468–71.

bioone.org.colorado.idm.oclc.org (Atypon), doi:10.1614/0890-037X(2004)018[1468:NAFEDA]2.0.CO;2.

Westbrooks, Randy G., and Robert E. Eplee. *Early Detection and Rapid Response*. 2011, pp. 169–77.

Westman, Walter E. "Park Management of Exotic Plant Species: Problems and Issues." *Conservation Biology*, vol. 4, no. 3, Sept. 1990, pp. 251–60. *Wiley Online Library*, doi:10.1111/j.1523-1739.1990.tb00286.x.

Wiggins, A., and K. Crowston. "From Conservation to Crowdsourcing: A Typology of Citizen Science." *2011 44th Hawaii International Conference on System Sciences*, 2011, pp. 1–10. *IEEE Xplore*, doi:10.1109/HICSS.2011.207.