INVASIVE SPECIES EDUCATION

AND CITIZEN SCIENCE

IN WASHINGTON STATE

by

Kenzi Smith

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Kenzi Smith

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by

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Edward Whitesell, Ph. D.
Member of the Faculty

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Date

Abstract

Invasive Species Education and Citizen Science in Washington State

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Invasive species management is difficult and expensive, and citizen science has the potential to help managers monitor invasive species for little cost. The Washington Invasive Species Council (WISC) receives reports of invasive species from the public as a sort of casual citizen science monitoring program, and also conducts invasive species outreach efforts, some of which promote the reporting system. The goal of this research is to determine how to improve invasive species outreach and citizen science monitoring programs using WISC as a case study by asking: how are reporters finding out about the species they report and WISC's reporting form, and how familiar are they with WISC's outreach slogans? An online survey including these questions was emailed to people who had previously reported an invasive species, and the results were analyzed for any trends. The most notable results were that invasive species reporters demonstrated a high degree of environmental concern, and the internet was the main way people learned about invasive species and the reporting form. The outreach slogans were not well known.

This research found that invasive species outreach and monitoring programs can be improved by better incorporating research in environmental education and science communication and using best practices from other citizen science programs. Specifically, appealing to people's emotions and senses of environmental concern may encourage them to take action by reporting invasive species, using the internet effectively is vital for outreach, and the quality of the data collected by invasive species reporters could be improved by validating reports and providing training to reporters.

WISC and other agencies can use these methods to improve their outreach and citizen science monitoring programs, which will increase the ability of citizen science to aid invasive species managers in monitoring and combating invasive species.

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Chapter 1: Introduction

Invasive species are a worsening problem in the era of globalization. Government agencies that are responsible for managing invasive species do not have the ability to keep them entirely in check, lacking the funding. The use of volunteers is one way government agencies can supplement their paid staff to get more work done in combating invasives.

In addition to using volunteers to physically remove invasives, volunteers can be used to conduct science. Citizen science can be used to monitor the distributions and new introductions of invasive species, providing better information to government agencies that they couldn’t necessarily afford to collect with paid technicians. This data can be used to decide where to focus efforts on combating invasive species, or to leverage more funding for invasive species control programs. And perhaps most importantly, citizen scientists can also be the first detectors of a new invasive species. Detecting new invasions early on is important, as only in the earlier stages of an invasion can an invasive species be eradicated completely, before it propagates too much and spreads too far.

While this partnership between citizen scientists and agencies combating invasive species could be very beneficial to the environment by slowing or even sometimes halting the spread of invasive species, little is known about how to maximize the effectiveness of invasive species citizen science monitoring programs using outreach and education programs. This thesis seeks to address this knowledge gap by looking at the Washington Invasive Species Council (WISC), a Washington state agency that conducts invasive species educational outreach and runs a citizen science-based monitoring program. This study, while restricted to Washington, could impart lessons applicable to invasive species outreach and citizen science monitoring programs in other regions as well. By improving the outreach conducted as a means of improving the partnership between agencies and citizen scientists, invasive species monitoring and management can be improved, helping to protect ecosystems from the harmful impacts of invasive species.

Many species, when introduced to a new area that is climatically very different from their home range, will not be able to survive, much less thrive, in these new ecosystems. These species would be considered exotic, but a species isn't truly considered invasive unless it is able to thrive in its new environment and propagate itself effectively. An invasive species must also pose some sort of harm: either harm to human health; economic harm; or harm to the health of the ecosystem it has invaded. Any living thing—plant, animal, bacteria, fungi, virus, etc.—can potentially be an invasive species. Additionally, invasive species have a specific legal definition in Washington State as defined by section 79A.25.310 of the Revised Code of Washington. They must be exotic/alien/non-native; they must be harmful in some way; and they must be capable of spreading beyond human control. However, agricultural plants and animals are exempt.

Invasive species are detrimental to ecosystem health (Downey & Richardson, 2016; Schmitz & Simberloff, 1997; Simberloff, 2005). The costs of managing them and the economic losses from damages cost an estimated total of $137 billion annually in the U.S. (Washington Invasive, 2009). Wherever possible, eradication is the goal, such as with the Washington Department of Fish and Wildlife's efforts to eradicate a population of African clawed frogs in stormwater ponds in the South Puget Sound (Pleus, 2017). For species that are so widespread such that eradication is not possible, managers will make decisions on a local basis about what control efforts to prioritize. Washington's Noxious Weed Control Board uses a classification system that reflects this thought process—class A weeds are not widespread and eradication is mandatory; whereas class C weeds are widespread and control is decided on a county-by-county basis.

The increasingly rapid spread of invasive species is an issue of growing concern among ecological conservation professionals. While all species have some natural ability to shift their ranges on their own and this process has happened countless times through the long history of life on Earth, advances in transportation technology are responsible for drastically increasing the distance, speed, and frequency of the movement of species. Some of these species are introduced intentionally, as pets, garden plants, etc.; but many of them are transported by humans completely unintentionally. For example, wood-boring pests can be transported in campers' firewood, or wooden packing materials used in long-distance shipping. Imported nursery stock can be unknowingly infested with a plant disease, or insect pest. Boaters can transport aquatic invasive species on the hull or the inside of their boat. Hikers can transport clinging seeds, small invertebrates, or disease-causing fungi in their boots or other gear.

Unfortunately, many people simply aren't aware that what they are doing is facilitating the spread of invasive species, or even that introducing invasive species is a bad thing. Hence the existence of programs like invasive species councils, some version of which can be found in several U.S. states. States that don't have an invasive species council will have some state departments, such as Agriculture, Ecology, Natural Resources, Fish and Wildlife, etc. that may share responsibility for combating invasive species and educating the public about regional invasive species issues.

Invasive species councils are comprised of employees of various relevant state agencies, and potentially also Native American Tribes, county or city governments, or even private industries. The councils are formed to coordinate all these varying stakeholders who have an interest in combating invasive species. Then they collectively decide which invasive species to focus their funding and efforts on, including which species to target for outreach campaigns. The Washington Invasive Species Council (WISC) is one such council, with twenty-one members representing different agencies, regions of the state, and Tribes.

WISC is responsible for promoting invasive species-themed outreach campaigns and for taking other measures to educate the public about invasive species. Common educational avenues include social media, having outreach booths at public events, and volunteering to give educational presentations to interested groups such as classes and various organizations. WISC also maintains and regularly updates a top 50 list of priority species, featuring the species considered by the experts to be the biggest threats to the state in terms of ecological and/or economic harm. Some of these species are present in the state already, and some are not, but are expected to probably enter the state at some point. WISC has information on these species on its website (invasivespecies.wa.gov) and through its digital application for mobile devices (app), “WA Invasives,” which is freely available to the public. Both the website and the app also feature a reporting form for the public to report sightings of these invasive species on the top 50 list—a sort of informal citizen science program. However, WISC does not currently have a system in place to train the public to identify and report sightings of invasive species, unlike many other programs designed to harness citizen science for biological monitoring.

Citizen science programs are a way for volunteers, mostly amateurs, to assist pros and experts in gathering scientific data. Although the term “citizen science” wasn't first used until the 1990s, the usage of amateur volunteers to do science has a long history: the Audubon Society's annual Christmas Bird Count dates back to the year 1900. But recent citizen science programs are expanding on the concept, with more programs especially since the 2000s (Bois, Silander, & Mehrhoff, 2011), more types of data, and more volunteers than ever helping out. (Cohn, 2008). People of all age ranges, even young elementary school kids, can participate successfully, with only a few projects using specific groups of volunteers like scuba divers or high schoolers (Cohn, 2008; Cunha et al., 2017). This wide range of participants is possible because volunteers aren't given tasks that would require a lot of training or specialized knowledge, like analyzing data or writing reports (Cohn, 2008); instead, they typically only acquire raw data in the form of either samples or observations (Cunha et al., 2017). Most citizen science programs do biological monitoring because of the relative ease of the data collection for the volunteers (Cunha et al., 2017). Many of these biological monitoring programs focus on invasive species, such as WISC’s monitoring program.

While plenty of research has been done on citizen science programs and how to conduct effective environmental education and science communication campaigns (as will be demonstrated in the next chapter of this thesis), little is known about how these intersect, specifically how invasive species education and outreach might lead to increased and more effective citizen participation in invasive species monitoring programs.

To begin to address this gap, this study seeks to address this lacuna by asking how WISC's current outreach methods affect citizen participation in its invasive species sighting report system.

The WISC has little information about how to use effective outreach to better engage the public in monitoring and gathering invasive species distribution data. It previously had no data that could be used to determine which outreach initiatives promoted by the Washington Invasive Species Council are best known by reporters of invasive species sightings, and how different outreach methods correlate with these reports. Therefore, this thesis asks the following question: How are reporters of invasive species sightings learning about invasive species and the reporting program, and how familiar are they with WISC's slogans? A short survey was sent to previous invasive species reporters to ask them how they learned about invasive species and the reporting form, and which outreach slogans they were familiar with. At the request of WISC, a fairly open-ended question to allow people to express their sentiments about why they participated the reporting program was also included.

The results from 197 survey responses from prior invasive species reporters from across the state showed few connections between WISC's outreach efforts and participation in the reporting program. While WISC's web site does play a large role in educating citizen reporters about invasive species, other WISC outreach methods played little role. Reporters usually found out about the species they reported after conducting an internet search, and generally these internet searches were how they found out about WISC. WISC's data set of invasive species sightings also suffers from some inconsistencies in recording and the lack of distinction between validated and unvalidated reports.

The research presented in this thesis provides the basis for a number of recommended improvements to the current WISC invasive species reporting program. WISC can improve its invasive species outreach efforts and citizen science programs by better incorporating research in environmental education and science communication and by using a developing set of best practices derived from other citizen science programs. Many reporters demonstrated a sense of environmental concern that led them to report the invasive species, so fostering this concern about the ecological harm done by invasive species can be used to encourage greater participation in the reporting system. Due to the large role of the internet in educating the public about invasive species, making full use of technologies like the internet and social media is important to have information on invasive species available when the public wants to learn more. Telling stories about science instead of just conveying facts, and appealing to emotions by encouraging members of the public to feel like their participation matters, are primary ways to increase the effectiveness of outreach and use it to encourage the public to take action, such as by reporting invasive species sightings. The quality of the data collected can be improved by recruiting and training volunteers and having a data validation system in place to improve species identification accuracy and make the species distribution data useable.

Other agencies and other states will have their own unique programs with their own strengths and weaknesses that may differ from those of WISC. While these recommendations are specific to the needs of WISC, many will likely apply to other agencies and programs as well, or aid in the development of new programs. By improving these outreach and citizen science monitoring programs, the public can better help combat invasive species and protect natural environments.

The following chapters describe this research and findings. Chapter 2 reviews and analyzes the literature on the subjects of citizen science, environmental education, and science communication. Chapter 3 reviews three case studies of other invasive species citizen science monitoring programs to draw lessons from what makes them work. Chapters 4 and 5 cover the methods and results of this research, describing the survey and how results were analyzed, and reviewing some of the comments survey respondents left. Chapter 6 discusses these findings in the context of the previously reviewed literature, using prior research to explain possible reasons for these findings. Chapter 7 concludes this thesis with a summary of the most important lessons learned from the literature, case studies, and thesis, as well as recommendations for future research to gain a better understanding of this subject.

Chapter 2, the literature review, covers literature from three fields: citizen science, environmental education, and science communication. The first section on citizen science will cover why citizen science is a popular tool for collecting data, and the advantages and disadvantages it offers over traditional science. This literature provides both discussions of specific programs and analyses of multiple programs to draw generalizations of how to make citizen science work, and tends to concur that citizen science is a valid tool for collecting data. The section on environmental education reviews and compares some of the more prominent models of how environmental education works. The role of environmental education in changing people's behavior is generally seen as some variation of the basic model that education changes attitude which changes behavior, though the simplicity of this model is criticized and other more nuanced and complex models are provided that build on it. While all the models provided may individually be too simplistic to work entirely on their own, when compared to each other they can offer some insight into people's environmental behaviors. The literature on science communication provides a number of methods and insights for communicating science to a non-scientist audience. WISC is a government agency, but communication from a government perspective is not covered well by the literature. The literature often discusses how researchers can communicate their findings effectively with the public—though this information is often as equally applicable to government agencies as it is to researchers. While plenty of literature exists on each of these three discrete subjects, the overlaps between them are sparsely covered.

Chapter 3 will look at case studies of three successful invasive species citizen science monitoring programs—IveGot1, Invaders of Texas, and the Invasive Plant Atlas of New England (IPANE)—and compare them to each other and to WISC's monitoring program. These programs provide different levels of training for volunteers, with IPANE and Invaders of Texas offering more structured participation including registration and required training at events offered multiple times a year. While costlier to the program, these trainings likely offer the benefits of improving volunteers' invasive species identification abilities. These programs also take different steps to ensuring high quality data, such as limiting the range of reportable species to ones that are easier to identify, requiring staff to validate reports through a photo of the invasive, and simplifying protocols to make them easier for volunteers to handle.

Chapter 4 describes the methods used to research how reporters of invasive species sightings learned about the species and the reporting system, and how familiar they might be with WISC’s outreach slogans. The survey asking these questions was sent via email to a purposively selected sample of reporters from the incomplete archives of past invasive species reports from 2009-2013 and from 2016-2017. The survey also included a comment box allowing the respondent to explain what led them to report the species to WISC. The results were analyzed to compare differences in responses between counties across the state and to compare the results to which species was reported.

Chapter 5 presents the results, which primarily demonstrated the importance of WISC's web page in educating people who wanted more information on invasive species or how to report them. WISC's and other web pages were the most common information sources overall, while social media, printed media, and in-person outreach did not reach many reporters, and most reporters were not familiar with WISC's outreach slogans. Survey results did not vary significantly by which species was being reported, and the notable variations were likely due to social media posts that led to more reports of certain species. Many limitations of the study design became evident in the results, as will be discussed in this chapter.

Chapter 6 discusses how the literature on environmental education and science communication helps to explain many aspects of the results and also many ways in which WISC might improve its outreach and citizen science efforts. Data validation and volunteer training modeled after other citizen science programs could help improve the quality of WISC's invasive species distribution dataset. The survey results emphasized the importance of the internet in communicating science, as the internet is how most people search for scientific information. The reporters' positive sentiments in the survey results reflect positive environmental attitudes, and their decisions to report exemplify positive environmental behaviors and good internal loci of control. WISC's use of a communications professional and updating of its information are good practices in science communication. But without further analysis of WISC's communications themselves, little else can be said about how effective WISC's outreach efforts might be or how they could be improved.

Chapter 7 will summarize the findings of this research and suggest other lines of questioning that could be pursued to learn more. Invasive species are expensive to manage, and citizen science is a tool that can help monitor invasive species where funding is lacking. The literature and findings suggest that the data quality of citizen science programs can be improved by validating data and training volunteers, and greater participation in citizen science might be encouraged by improving the appeal of the outreach efforts. The recommendations this chapter provides are tailored to WISC, but could be as easily applicable to any invasive species outreach or citizen science monitoring program. Improving invasive species outreach and monitoring programs can increase the usefulness of citizen science in helping agencies combat invasive species.

Chapter 2: Literature Review

This research seeks to learn how invasive species management agencies can make the most of citizen science by attempting to determine what outreach efforts WISC reporters have come into contact with, or where else they might be learning about invasives if not through WISC. The literature can't answer these questions directly, but can be used to help interpret the results of this study. But there is a gap in the literature, as invasive species education and outreach is not well-written about. This research will help address this existing gap in the literature, and must draw from three often interrelated subjects that are more often written about: citizen science, environmental education, and science communication. This chapter covers the literature of each in turn to provide a basis for understanding the results of this study.

Understanding citizen science better can inform WISC's place in the crowd of citizen science programs out there. There are few specific citizen science programs with much written about them, but a greater amount of literature on citizen science in general. While citizen science has its advantages over science done by professionals, its validity is sometimes questioned due to the lesser training of volunteers compared to professionals. But there are ways citizen science programs can accommodate the abilities of their volunteers, making citizen science overall a useful tool for low-cost, large-scale science.

Environmental education has a heavy emphasis on models of knowledge, attitude, and behavior that may vary quite a bit but usually relate back to how these three factors interact. Understanding these interactions is important to informing decisions of where and how to intervene to influence people's behavior with regards to the environment. This knowledge could explain the relationship between WISC's outreach methods and how they might impact participation in the sighting report system.

Science communication is a discipline that can overlap with environmental education, but focuses more on how to explain complicated scientific subjects to the non-scientist public, and may not necessarily be about environmental issues. The lessons learned from science communication are different from what environmental education offers—like how the use of the internet can connect scientists directly to the public, and how anecdotes can illustrate facts in a way that makes them more engaging. Thus science communication also offers valuable information to WISC to improve outreach.

Citizen Science

Why use citizen science?

Citizen scientist programs are a great way to gather data because the volunteers tend to live across large geographic distributions, and thus can more easily cover larger areas than more centrally located scientists. This gives citizen science data collection an advantage over data collection using paid technicians (Bois et al., 2011; Cunha et al., 2017). Volunteers can also gather a much larger volume of data than otherwise possible, because funding (often from grants) is limited, and teams of paid technicians are far more expensive to maintain than teams of volunteers, but citizen science programs will only require enough paid staff to manage the program (Bois et al., 2011; Bonney et al., 2009; Cohn, 2008; Delaney, Sperling, Adams, & Leung, 2008)**.**

Since volunteers can cover larger areas and these programs can run year after year, the data can be used to analyze large-scale geographic and temporal trends, such as population trends, shifts in distribution, et cetera (Bonney et al., 2009; Cohn, 2008).

Establishing these geographic and temporal trends often requires the large volume of data that might only be affordable with citizen science programs. However, it is not necessarily the case that all citizen science programs will generate large volumes of data—for example, the IveGot1 program in Florida initially had very low participation rates, for reasons that will be discussed in the next chapter of case studies (Falk, Snow, & Reed, 2016).

These large-scale trends can then be more deeply researched with more focused, professional studies (Bonney et al., 2009). These more focused studies done by experienced professionals can address a major concern about citizen science—questions of the validity of the data.

Validation and limitations of citizen science.

Much has been written on the validity of data collected by citizen scientists (Bois et al., 2011; Crall et al., 2011; Delaney et al., 2008)—a strong concern in a field where adherence to strict protocols is considered vital to obtaining valid data. There are concerns that because volunteers are not professionals and may have limited training, their ability to identify a species correctly may not be as good as that of a professional, as was found in a study by Crall et al. (2011), or that because they are volunteers they may be less motivated to strictly follow data gathering protocols when it is inconvenient, difficult, or tedious, as occurred in a study by Delaney et al. (2008).

It is intuitive that professionals and experts will have better identification skills than volunteers. The literature agrees that professionals are better at submitting accurate reports than amateur volunteers—typically in the context of identifying a species of animal or plant correctly—but that overall, volunteers are accurate enough for their data to still be useful, especially considering the cost effectiveness (Bois et al., 2011; Cohn, 2008; Crall et al., 2011; Delaney et al., 2008). A 2011 study by Crall et al. compared the invasive species identification skills of professionals with volunteers, using very thorough statistical analyses comparing treatment to control groups. Volunteers could identify the presence of an invasive plant accurately 72% of the time, and misidentified a species only 1% of the time. Compared to the professional's 88% identification rate and <1% misidentification rate, the volunteers compared fairly well, especially considering that the plants were only misidentified a miniscule number of times, and most of the inaccuracy was simply failure to report a plant that *was* there. For monitoring programs that don't use established plots or true absence data, failing to report an invasive doesn't diminish data quality in the same way as reporting something that isn't there—so results like those found by Crall et al. (2011) would be very promising for many citizen science programs. And, importantly, Crall et al. found that volunteer's self-reported experience and confidence in identifying invasive species was a strong predictor of their actual I.D. abilities (2011). So it's not as though there are no ways to estimate whether a program's volunteer base has the skills needed to do the work.

To improve the identification skills of volunteers, some degree of training is present in a number of citizen science programs (Bois et al., 2011; Crall et al., 2011; Delaney et al., 2008; Gallo & Waitt, 2011). However, Cunha et al., in a meta-analysis of citizen science projects between 2005 and 2014, found that most projects did not involve training for the volunteers (2017), presumably for the same reasons that citizen science is an appealing route in the first place: lack of funding. But that's not to say that volunteers aren't useful if training isn't provided. Crall et al. found that many volunteers already possessed some skills, whether self-taught or from prior formal training, in species identification (2011).

Concerns about volunteers not following protocols consistently due to difficulties did manifest in a study by Delaney et al., though to be fair many of those volunteers were young children (2008). But while in some programs the data collection demands may be too much for volunteers to handle, it's more than possible for the data to still be useful, or for the necessary adjustments to be made (Gallo & Waitt, 2011). Several sources stressed the importance of avoiding overly complex data collection protocols. Data collection protocols should be clear, simple, and logical in order to help the project be as successful as possible (Bonney et al., 2009). To achieve this, a developing program can test data collection protocols on a smaller group before expanding to the rest of the program (Crall et al., 2011). And even after a program is up and running, the managers can still periodically evaluate the protocols by testing the accuracy levels of samples of the volunteer base, and adjust the protocols as needed (Bonney et al., 2009).

In addition to setting up good protocols when developing the program, the subsequently collected data can be validated to varying degrees. A system of electronically submitted reports can be validated especially easily due to the possibility of automatic validation in addition to expert review. Automatic validation means reports can be flagged for further review if something is off—say, a species is reported well outside its typical range (Bonney et al., 2009). If photos are included with a report, a professional working for the program can then validate whether the species was identified correctly (Bois et al., 2011). Crall et al. strongly recommend that programs require volunteers to either collect a specimen, or at least take a photo for verification (2011). They also recommended that programs give specific instructions for how to take good identifying photos for particular categories of species (2011). Unfortunately, adding a set of steps on how to take good photos—steps which will differ depending on the type of species—does add another layer of complexity to the data collection protocols. And, as established, data collection protocols ought to be simple in order to work well for volunteers. But what isn't considered by the literature is the importance of good identifying photos against the importance of simple data protocols.

To accommodate volunteers’ somewhat lessened abilities to accurately identify invasive species, a program can always limit which species they ask volunteers to look for. It is a good idea to focus on only teaching identification of a limited number of easily identifiable species for the sake of accuracy, leaving the more difficult species to the professionals (Crall et al., 2011).

If volunteers need simple data protocols and can only handle identification of a limited range of species, does that limit the usefulness of citizen science? It would seem so, but it isn't something that the literature seems overly concerned about. Bonney et al. felt that citizen science is overall a great success, and a highly valuable tool, and that it is possible for citizen science projects requiring more skilled volunteers to be successful, but that they will require a proportionate investment in training of those volunteers (2009). And even if there are restrictions on what knowledge can be gained through citizen science, the knowledge gained is still valuable. For example, volunteer-collected data on giant reed (*Arundo donax*) distribution greatly expanded the previously-known distribution of the species, showing that it was in 58 more counties than previously known (Gallo & Waitt, 2011).

Environmental Education

Environmental education has a strong focus on trying to understand how to use education to change people's behavior. One pattern quickly emerges from reviewing the environmental education literature, namely that most papers reference at least one or two of these topics: environmental knowledge/awareness, environmental attitude/emotion/concern, or environmental behavior/action. Different papers use different terms to refer to concepts that are quite similar. Some papers break down these ideas into more complicated parts, or add new terms, but generally these three concepts are very prevalent (see Bamberg et al., 2000; Carmi, Arnon, & Orion, 2015; De Young, 1993; Duerden & Witt, 2010; Hungerford & Volk, 1990; Kaiser & Fuhrer, 2003; Kollmuss & Agyeman, 2002; Pooley & O'Connor, 2000; Schultz, 2000; Short, 2010). The discussion of these models will be organized by the degree to which they focus on these three different factors, since attempts to structure the discussion in other ways resulted in artificially splitting the discussion of each model.

As authors construct models to explain the relationships between these three ideas, they frequently reference, criticize, modify, and build off of previous models. The oldest and most basic model of the relationship between these three variables, shown in Figure 1, is this: environmental knowledge causes changes in environmental attitudes which causes changes in environmental behavior (Hungerford & Volk, 1990; Kollmuss and Agyeman, 2002). Essentially, if people know what problems exist and what causes them, they will feel concerned and take steps to address the issues however they can.

Figure 1. Basic model of environmental education. The simplistic model often referenced, from Kollmuss & Agyeman (2002).

This basic three-part model at first seemed fairly intuitive and reasonable, but evidently is far too simplistic to actually work as a model, and is not supported by research (Hungerford & Volk, 1990; Kollmuss & Agyeman, 2002). But, despite how the model was criticized, it was very heavily referenced. It has become a frame of thinking that authors use as a starting point from which to build more realistic, complex models.

Hungerford & Volk's heavily-cited landmark paper (1990) attempted to create a newer, more accurate model by greatly deepening the complexity of the variables that contribute to a person's environmental behavior (see Figure 2). They proposed three categories: entry-level variables, which include sensitivity, environmental knowledge, and attitudes; ownership variables, which describe how environmental issues feel personal to someone; and empowerment variables, which essentially reflect a person's belief that the things they do matter and can make a difference.

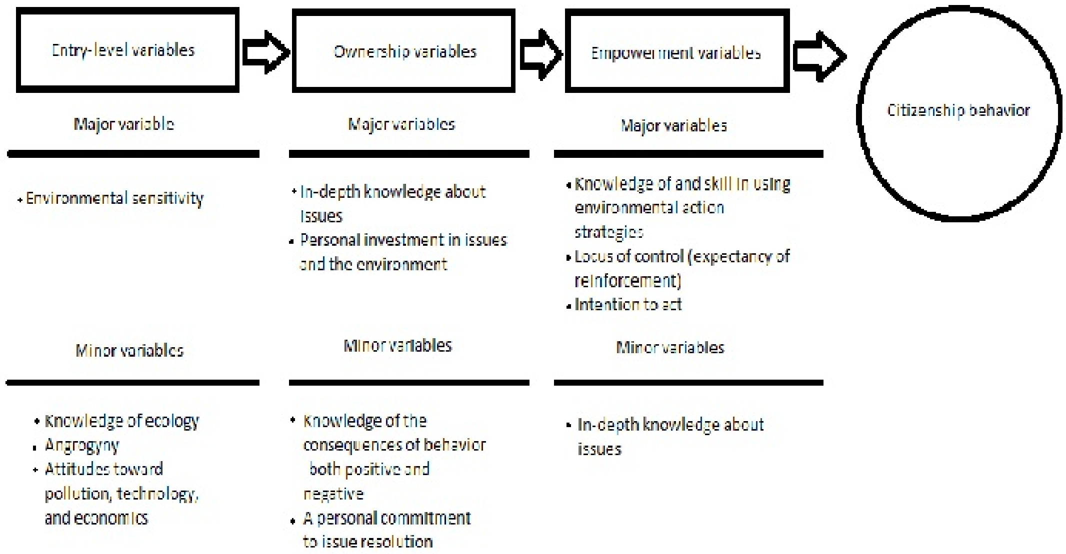

Figure 2. Recreation of environmental education model proposed by Hungerford & Volk (1990). Major variables have a stronger impact on "citizenship behavior"—which is essentially positive environmental behavior—while minor variables have a lesser impact.

Ownership variables are particularly important to promoting good environmental behavior (Hungerford & Volk, 1990). Entry-level variables represent a sort of combination of the environmental knowledge and environmental attitude concepts, which are more heavily discussed in later models. Ownership variables and empowerment variables differ more from the old basic model, but still the same concepts came up in later models as well. A few sources discussed barriers to ownership variables—though in different terms. Unfortunately, since environmental degradation is a fairly slow process, it can be hard for it to feel like a very real and immediate threat to people (Carmi et al., 2015). The "time lag" between action and the resulting damage, the remoteness of some affected areas, and the subtlety of some of the damage makes it difficult to perceive the connection and feel strongly about it (Kollmuss & Agyeman, 2002).

Empowerment variables include the “internal locus of control,” a concept meaning that one believes in one's ability to be successful and make an impact with one's actions. Whereas an external locus of control, the belief that only other people can bring about change, is a barrier to positive environmental behavior (Kollmuss & Agyeman, 2002).

Focus: environmental knowledge.

Kaiser & Fuhrer's model (see Figure 3) focused on breaking down how different types of environmental knowledge impact behavior. The types of environmental knowledge are: declarative knowledge, or how things ought to be; procedural knowledge, or what can be done to change things; effectiveness knowledge, or an understanding of the impact of different pro-environmental behaviors; and social knowledge; or an understanding of what is normal or not in society. A lack of pro-environmental behavior is due to a lack of convergence and synergy of these types of different knowledge, and so just increasing knowledge is not enough to prompt positive environmental behavior if these four types of knowledge are not working together well (2003). Otherwise, this model was just a version of the knowledge > attitude > behavior model from the seventies, with a layer of added complexity primarily in the knowledge phase.

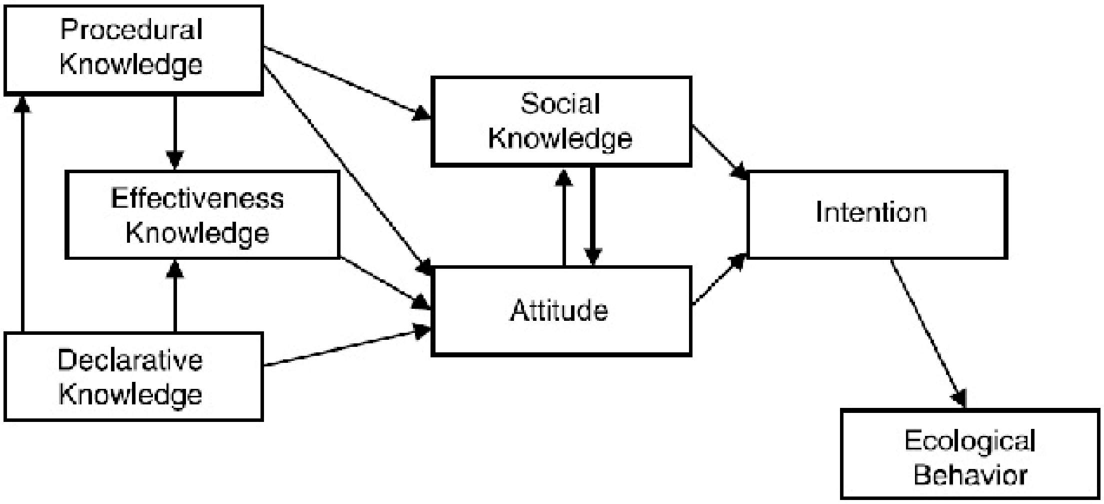

Figure 3. Model of environmental education proposed by Kaiser & Fuhrer (2003). This model shows how different types of knowledge work together to promote positive environmental behavior.

Focus: both environmental knowledge and emotion.

Several papers argue against relying too much on environmental knowledge alone to change behavior. In contrast to Kaiser and Fuhrer's model of knowledge types, Carmi et al. broke down knowledge into two categories: objective, meaning facts and terms; and subjective, which is more about understanding connections between things (2015). Subjective knowledge is much more important, since it has the most influence on environmental attitude—and by proxy, environmental behavior, since environmental emotion was a big predictor of environmental behavior. Their study would suggest that subjective knowledge, while still having a small impact on emotion, is not a reliable predictor of environmental behavior. The relationship between knowledge, attitude, and behavior is not as simple and straightforward as the old basic model. Carmi et al.

conclude that knowledge can have some indirect effects on behavior, but only when mediated by emotion, which knowledge can impact to some degree (2015).

Another model centering around environmental knowledge and emotion concludes that emotion is perhaps the more important variable (Pooley & O'Connor, 2000). While this model used slightly different terminology and distinguishes "emotion" from "attitude," the message is still in agreement. Emotion is a strong predictor of attitude both on its own and when combined with knowledge, and emotion is a bigger influence on behavior than knowledge on its own. Thus both knowledge and emotion need to be targeted by environmental education, and knowledge alone is not enough to promote change. (Pooley & O'Connor, 2000).

A third study provides a different angle, emphasizing how knowledge is obtained. (Duerden & Witt, 2003). Environmental education experiences can be put into two categories: indirect experiences (such as a classroom lecture) and direct experiences (such as a trip into nature). Direct experiences have a much greater impact on attitude and behavior than the indirect experiences (Duerden & Witt, 2010). Generally, environmental attitude has a bigger impact than knowledge on environmental behavior, similar to findings from Carmi et al. (2015). Also like what Carmi et al. found (2015), there is a relationship between knowledge and behavior—but only when the indirect learning experience to increase knowledge is followed by the less structured, more interactive direct learning experience. These direct, interactive learning experiences give people the chance to apply their new knowledge immediately, so their environmental knowledge can develop alongside environmental attitude, and both will end up influencing environmental behavior to similar degrees (Duerden & Witt, 2010). This is a somewhat unusual finding, since often environmental attitude is found to have a greater impact on behavior than knowledge, not a similar impact.

A final model presents three types of “interventions” that can successfully induce lasting behavioral changes using: information techniques, positive motivational techniques, and coercive techniques (De Young, 1993). Information techniques are nothing new—the idea that if people understand a problem, they will want to solve it, and if they know how to solve it, they will try to. This derives from the classic model in which environmental knowledge eventually leads to better environmental behavior. Positive motivational techniques involve social support, rewards, or incentives to get people to change by making the change personally appealing to them. This is a new idea thus far in the consideration of these models—it isn't exactly about knowledge, or emotion, but does have a direct impact on behavior. The final category, coercive techniques, would involve restricting choices either legally, or with social pressure, to prompt a behavioral change. Social pressure can be used to induce guilt or a sense of duty (De Young, 1993). While not explicitly framed as such, this is a sort of appeal to environmental emotions.

Focus: environmental attitude

Schultz's model emphasizes environmental concern (attitude) the most, trying to understand it through the lens of three different categories of personal attitudes: egoistic, altruistic, or biospheric (2000). Egoistic people view themselves as independent from nature and other people; altruistic people view themselves as connected with others; and biospheric people view themselves as connected with all living things. But no particular view is a signifier of how much environmental concern one will have; only the ways in which it will manifest. An egoistic person may still have a great deal of environmental concern towards issues that affect them personally. This model is a little different in that it doesn't attempt to explain which factors influence behavior the most—and so neither does it talk about how emotions relate to behavior, which was otherwise a strongly recurring theme among these models.

However, one should not credit environmental attitude with total control of environmental behavior, as environmental concern (attitude) is less of a direct influence on behavior, and more of an important indirect influence (Bamberg, 2003). Still, environmental attitude is a very important influence on behavior, though not necessarily a direct cause of behavior (Bamberg, 2003).

The mother of all models.

Kollmuss & Agyeman's model (2002) is the most ambitious and complicated one yet. The authors noted that the influences on environmental behavior are so complicated that a single diagram representing it either won't be accurate or will be too complicated to make sense and be useful. Thus their model is less complicated than reality, but perhaps detailed enough to be useful (see Figure 4).

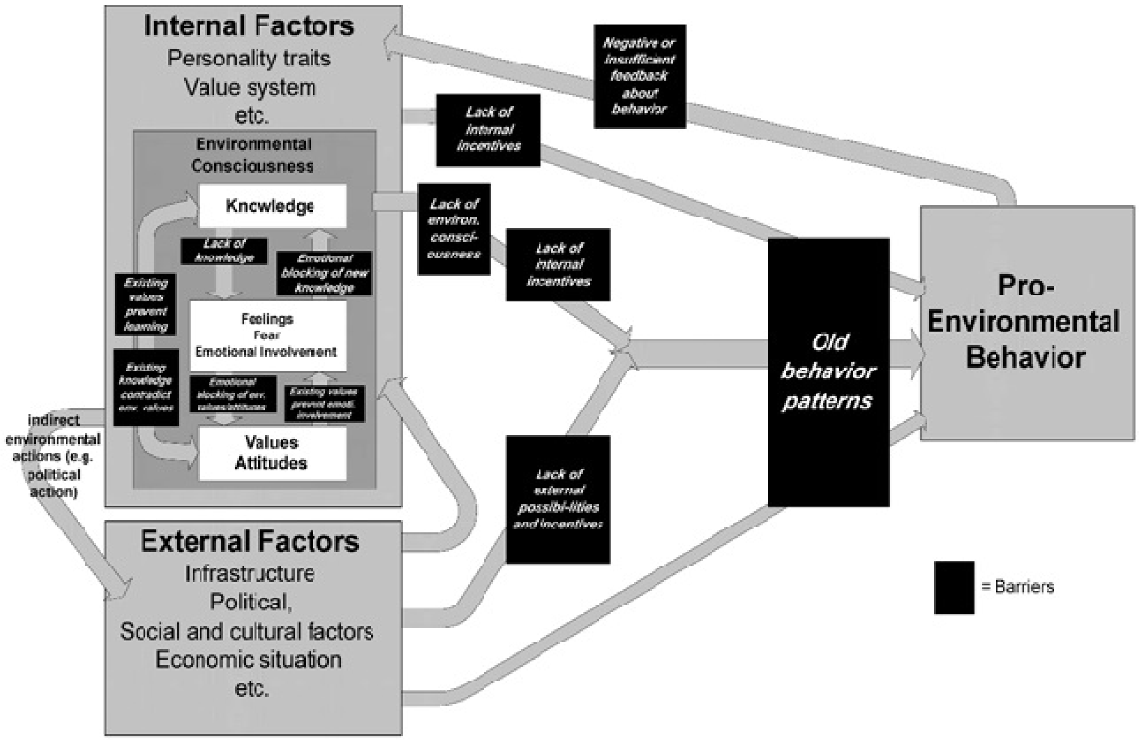

Figure 4. Model of factors influencing environmental behavior proposed by Kollmuss & Agyeman (2002). The small white-on black text within the "Environmental Consciousness" block, going clockwise from the top, reads: Lack of knowledge; Emotional blocking of new knowledge; Existing values prevent emotional involvement; Emotional blocking of environmental values/attitudes; Existing knowledge contradict environmental values; Existing values prevent learning.

Having an infrastructure available to support pro-environmental behaviors is important, and the effect of economic factors is complicated and not well-understood. Economic incentives may also be a factor, like De Young's concept of positive motivational interventions (1993). The "cultural values" aspect of this model is also comparable to De Young's "social support" factor as a form of a positive motivation. However, while these incentives and values can motivate pro-environmental behavior, this behavior then won't necessarily stem from positive environmental attitudes, or environmental concern (Kollmuss & Agyeman, 2002). So, the positive behavior may only last as long as the incentive is in place, resulting in the opposite of the hoped-for effect, which is change without the need for repeated interventions.

Science Communication

Another discipline related to environmental education is science communication, due to the strong potential for overlap. But, whereas environmental education often focuses on models of how education changes people's environmental attitudes and behaviors, science communication doesn't necessarily have to be about environmentalism; it is more about how to effectively explain complicated scientific ideas to laypeople. A science communicator is someone communicating science to the public—scientists are not necessarily science communicators unless they attempt to explain their research or findings to the public. While not acknowledged by the literature, not all people attempting to communicate science to the public are, themselves, scientists, but for the purposes of this discussion they will still be considered science communicators.

Science communication is fairly heavily criticized by the literature. Not the concept of it—it’s considered to be very important—but rather in practice, as science is often not communicated particularly well (Weigold, 2016). Science communication suffers from a lack of familiarity with the audiences, complicated subject matter, and a lack of feedback from the public to help improve communication (Fischhoff & Scheufele, 2014); science communicators don’t pay enough attention to the large body of research on what makes public engagement efforts work (Nisbet & Scheufele, 2009); and science communicators focus too much on facts (Dietz, 2013). The literature has a lot to say about what science communicators do wrong, and some suggestions for how they could do better.

Getting information to the public.

Science communicators bear some responsibility for determining what information the public may need, and making it readily available. To assist the public in decision-making processes, science communicators ought to attempt to identify what information the public needs for making sound decisions and make that information available early on (Fischhoff, 2013; Richards, Belcher, & Noble, 2013). Organizations or individual scientists attempting to communicate science are responsible for knowing their audience, determining what their audience already knows, and designing their communication to meet the knowledge gaps of what they know and what they need to know (Fischhoff, 2013). Members of the public may not be aware that they are lacking in the information they need; thus, the agency must meet those needs before the public starts requesting better information (Richards et al., 2013).

Similarly, it is an organization’s responsibility to use the forms of communication that are best suited to reach their audiences. The public generally depends on outside sources for science information—because most people are not scientists, science is not something people learn about through their own direct experiences (Dahlstrom, 2014). Mass media (television, the internet, books etc.), organized education, and public participation in science are the three ways the public learns about science (Dietz, 2013) but here, mass media will be discussed primarily.

Sources of information are changing as new technologies develop. Scientists are now able to communicate directly with the public through social media platforms, as opposed to communications professionals having a hand in the releases of scientific information (Brossard, 2013). Television and internet dominate sources of information for science news and information. The internet is the more popular choice for users under 30, and the internet is the preferred choice when people want information on a particular science topic (Horrigan, 2006). Most of the literature is either neutral or positive about the role of changing technologies in science communication, as the internet allows science communicators to engage the public and correct misunderstandings and false claims directly (Brossard, 2013; Groffman et al., 2010). But despite how the internet can make direct communication easier, communicating with wide audiences has become more difficult over time as a wider range of content has become available, all of it competing for the public's attention with any science communication efforts (Nisbet & Scheufele, 2009).

Making communication clearer.

Scientists don't necessarily have training in science communication (Nisbet & Scheufele, 2009), and science is by its nature often complex. The complicated nature of science makes it inherently difficult to understand, and so breaking it down to make it clear to the public is one of the biggest challenges science communicators face.

Presenting information in a way that is intuitive to understand is the science communicator's job—subtleties that may confuse should be avoided, as they may mislead the public and confusion may discourage people from further engagement in a scientific issue (Richards et al., 2013). Excessive jargon, at least when being used without definition or explanation, ought to be avoided for this same reason (Brunson et al., 1992).

An approach, then, to making content understandable is to have a good understanding of who your target audience is, and customize any presentation for that audience (Hobbs, 2006). To get one's point across well, maintain a clear message at the center of any communication, repeat it, and keep everything brief. Repeating the main points at the beginning and end of a communication helps them sink in (Hobbs, 2006) somewhat like the introduction, body, and conclusion structure of essays. Repeating the basic message often will make a bigger impression on people (Jacobson, 2009).

Beyond just keeping information clear and easily understood, keeping it up-to-date is equally vital. Regular releases of new information on a scientific issue can help prevent the public from forming opinions on old news (Richards et al., 2013).

Values and disagreement.

The reasons why the public sometimes comes to different conclusions than scientists on scientific issues is a prominent issue discussed in the literature (Brunson et al., 1992; Dietz, 2013; Groffman et al., 2010; Nisbet & Scheufele, 2009). Science communicators cannot force the public to agree with them on everything and see every issue the same way—and this lack of agreement doesn't mean the public is ignorant. Science communication is heavily fact-based, but even universal agreement on the facts doesn't equate to universal agreement on an issue (Dietz, 2013). In reality, the public may have a good understanding of a subject and it is only their differing value system that causes them to process the same information and produce a different opinion (Brunson, 1992). Decision making requires consideration of both facts and values (Dietz, 2013) and it is personal values where people may differ the most. Environmental issues in particular are deeply tied to people's values and senses of right and wrong (Groffman et al., 2010), and a person's ideals, identity, and level of trust with a source of science information can have an even bigger impact on decisions than their knowledge of facts (Groffman et al., 2010). It is thus a false premise that controversy over a scientific issue is primarily about the public's lack of scientific knowledge (Nisbet & Scheufele, 2009). But science communicators focus too much on the role of science knowledge in the public's decisions on science (Nisbet & Scheufele, 2009); this focus on ignorance as the source of disagreement is a too-common assumption (Groffman et al., 2010).

And even when the public doesn't know as much, it's simply condescending for science communicators to look down on the public for it—an attitude that is all too common. This is a problem, because condescension is a powerful inhibitor to public engagement. Lack of information is not always the issue, and assuming so is underestimating the public's ability to think critically (Brunson, 1992). It's not realistic either, as even scientists don't make decisions purely based on facts. Scientists are still people, and their values can still influence their interpretation of facts in decision-making (Dietz, 2013). But this condescending view is appealing to science communicators because it means debates will be about facts, which can be easily proven or refuted, and not about values which are far more personal and subjective. This view leads science communicators to place more emphasis on educating people about the facts, thinking that this will resolve conflicts (Dietz, 2013).

One proposed solution to the conflicts caused by value differences is to try to establish common ground with those people with conflicting value systems; science communicators and the disagreeing public may still share some core values, or goals for the future. Emphasizing these common goals can facilitate cooperation with people with disparate value systems, or at least make them less combative. In the same way a science communicator ought to know their audiences' knowledge levels on science (Hobbs, 2006), a science communicator needs to be aware of their audience's social values and how they affect their views of a scientific issue (Brunson, 1992). However, this solution doesn’t necessarily work in all situations. If there were sufficient common ground in people's values in the first place, there wouldn't be a disagreement. But perhaps science communication shouldn't be seen as an effort to eliminate disagreements between people entirely but, rather, to reduce the disagreements to be fewer and due only to value disagreements rather than different understandings of scientific facts (Fischhoff, 2013).

Engaging communication.

There is a striking similarity in the concepts of how science communication is too fact-based and not enough value-based, and how science communication is not telling stories well. However, most of the literature doesn't directly consider storytelling, narratives, and anecdotes and their power to communicate with the public.

Anecdotes—stories illustrating an example of something—are far more effective at engaging the public than raw data. Stories or narratives are easier for people to understand, since they demonstrate their own claim—which makes them powerfully persuasive—and they are the format through which non-scientists generally receive scientific information (Dahlstrom, 2014). But narratives may be problematic, as they aren't scientific data and may be frowned upon by the scientific community as being more subjective than objective. They don't require citation or justification for a concept since the narrative itself exemplifies the concept. But in doing so, they can give the impression of an existing trend where there is none—only a single anecdote. Narratives have the power to be misused to mislead people, but they are also vital to engaging science communication (Dahlstrom, 2014). But how one would combat a misleading narrative used by others isn't discussed.

A few other sources approached this subject from different directions—such as how science communicators need to connect science to subjects that the public cares about, to make the science more relevant to the public on a personal level (Nisbet & Scheufele, 2009), and how being too fact-based also leads to telling poorer, less engaging stories (Dietz, 2013).

Though it takes a different approach on how to create engaging communication, a 2014 study by Milkman & Berger on what factors cause the public to share scientific findings had illuminating results that could aid in understanding how to make science communication more engaging. The authors contacted scientists who had recently published findings in scientific journals, and received over 800 responses of summaries of the work and findings. These summaries were then shown to 7000 people who rated each summary on factors including their likeliness to share the finding with someone else. Co-authors each wrote their own summary, allowing some control for the type of science being done versus the way it was being described. Their findings, while not framed in terms of storytelling, reflected the same sorts of ideas. The summaries that were rated as more useful, interesting, and emotional to the public were more likely to be shared. An increase in emotional words increased the chance of being shared—as did positive scientific findings. People were also more likely to share findings that were about people in some way—like subjects such as business, psychology, and economics, which all have direct and obvious connections to people. Even words for people—like “adult,” “baby,” etc—resulted in an increase in the likelihood that of the summary of findings would be shared.

Conclusion

Citizen science, though not without some limitations, is an effective way to collect large volumes of scientific data for research on large-scale trends. Though professionals tend to collect higher quality data, the quantity of data collected by citizen scientists for free is often worth a slight decrease in data quality, and training programs, data validation, and simplified data collection protocols can help ensure good data quality. The steps taken by other biological monitoring programs to increase data quality will help programs like WISC achieve the best data quality possible.

The literature widely agrees that environmental attitude/emotion is a significant factor in changing environmental behavior, and environmental knowledge is perhaps a smaller influencing factor. Key differences between these models were the degree to which different factors like environmental attitude were credited with affecting environmental behavior, and how to break down and categorize the different key factors impacting environmental behavior. Though the many different available models used different terms and emphasized different factors in environmental behavior, largely they were more similar than they were different. The models were all focused on environmental education's main goal of trying to explain how to change environmental behavior, and they tended to relate back to the basic model: environmental knowledge changes environmental attitude, which changes environmental behavior. These models can help agencies like WISC understand how their outreach programs (attempts to change environmental knowledge) impact environmental behaviors like participation in the invasive species reporting system.

While science communication has some similarities with environmental education, the focus is more on how to make communication clear, accessible, and engaging. Science communication benefits from the rising popularity of the internet because it can connect scientists directly with the public, but a lack of simplicity and over-emphasis on facts can make science communication dense and unappealing to non-scientists. Using anecdotes to tell stories about science can help engage the public better in learning about science.

This research differs from the research conducted in the literature in a few notable ways. WISC's citizen science program recruits casual participants through its invasive species outreach programs, unlike most of the citizen science programs the literature describes, which more often recruit more involved volunteers directly into the program instead of as a secondary result of an outreach effort. Like much of the literature on citizen science programs, the data submitted by citizen scientists is being used by this research as part of the data set. But unlike the other research conducted, this research is not using this data to evaluate the success rate of the program such as in participation rates or species identification accuracy. Further, WISC differs as a matter of study because it historically has not provided trainings to its citizen scientists, so their source of information for how they are learning about invasive species is unknown and very important. In programs that provide training, even if participants come into the program with some knowledge, the program can ensure a higher degree of control over the information the volunteers receive. The literature on environmental education does not discuss invasive species as a subject matter at all, making this research unique in that way. This research does not attempt to generally model the links between education and behavior as the literature does, but instead seeks much more specific connections between sources of information and the subsequent behavior (i.e. reporting an invasive species). The literature on science communication mainly fails to address how to communicate effectively from the perspective of a government agency—something that this research touches upon by attempting to determine what outreach methods from a government agency might be most effective. The methods of this research do not derive from those in the literature, but rather were designed to discover in the simplest manner possible where citizen scientist participants were getting their information. Even this information is not usually sought by the literature except in some sources about science communication that cover avenues of communication.

The next chapter will delve deeper into citizen science, moving from the general to the specific by comparing three case studies of invasive species monitoring programs. These programs will be compared with WISC in terms of how they function and what works or doesn't work for them.

Chapter 3: Citizen Science Case Studies

There are many existing citizen science-based programs that monitor invasive species, but only a few that monitor a wide range of species over a large geographic area. Among the most well-known programs are the Invasive Plant Atlas of New England (IPANE), the Invaders of Texas program, and Florida's IveGot1 program. WISC's reporting system differs considerably from these programs because it is less formalized, with participation more casual, and lacking in trainings. However, it is similar in that it covers a range of species and a large area, i.e., the entire state of Washington. It is worthwhile to discuss and compare these programs and how they run, for WISC and potentially other invasive species monitoring programs could learn from the successes of these larger programs. While a look at these programs won't necessarily address the primary research question of how invasive species reporters are learning about invasive species etc., it will address the goal of this research—understanding how to improve citizen science monitoring programs to make them better tools for managing invasive species.

Volunteer Recruitment, Training, and Motivation

Volunteers are the backbone that allow citizen science to work. But how does a citizen science program get volunteers to join and participate? Volunteers are often motivated by concern for environmental issues, and a desire to do whatever they can to help scientists solve environmental problems (Cohn, 2008).

WISC's monitoring program as it exists now doesn't really have "volunteers," since participants aren't tracked and aren't asked to do anything in particular. Currently, WISC just passively provides them a couple of reporting pathways to use if they happen to encounter an invasive species. Still, WISC is recently (beginning in fall 2017) starting to provide invasive species trainings and promoting its invasive species reporting app at those trainings, so even without a formalized volunteer program, WISC could learn something from the other programs that do recruit participants more proactively.

IPANE and the Invaders of Texas programs take very active approaches to recruiting and training volunteers at periodic training events held multiple times a year. These training programs can both introduce new participants to the invasive species they'll be looking for, and refresh the memories and identification skills of ongoing participants. IveGot1 doesn't promote any training events, instead relying on its educational “IveGot1” mobile app and website resources to educate participants about invasive species, but it does encourage participants to join organizations like the Florida Exotic Pest Plant Council or a local Cooperative Invasive Species Management Area (IPANE, 2018).

The Invaders of Texas program requires participants to go through training before they can submit reports. This training is available as a series of educational modules and quizzes on its website or through in-person local workshops (Texas Invasives, n.d.). Many participants in the Invaders of Texas' training events are recruited from a separate program, the Texas Master Naturalist program. There would seem to be plenty of overlap among master naturalists and people who would make good, active, and interested candidates for an invasive species monitoring program. However, the Invaders of Texas program found that retention rates for workshop trainees were somewhat low—only 43% of trainees ever submitted invasive species reports (Gallo & Waitt, 2011). It is possible that many of the master naturalists participated in the Invaders of Texas trainings just to get training credits to apply to the master naturalist program, and weren't actually interested in participating in the invasive species monitoring. So recruiting from a master gardeners or master naturalist group might not work out as well as expected if the trainees are only using credits from the trainings to maintain their status within the program.

The Invaders of Texas isn't the only program to experience unexpectedly low participation rates—IveGot1 in Florida had even more trouble in the beginning. The IveGot1 program in Florida was originally focused entirely on finding invasive snakes, but participation in the program was very low. Pythons are difficult to find in the brush, which discouraged participants from putting much effort into searching for them (Falk et al., 2016). For volunteers who had very little success and may not have even found a single snake in a whole day of searching, it's understandable that they would lose motivation to try at all. Which is exactly what happened—volunteers' interest in doing the work faded over time, which is probably also due to the lack of other incentives to make their effort worthwhile (Falk et al., 2016).

But, later, the IveGot1 program was expanded to include monitoring for other invasive species, some of which were much more common. This was apparently done in order to give the volunteers a higher success rate of identifying and reporting something, which could then renew their sense of helpfulness. The program was expanded for this reason—to encourage them to continue searching for invasive species, which would hopefully result in more sightings reports of the invasive snakes that the program was originally intended to monitor (Wallace, Bargeron, Moorhead, & LaForest, 2016).

Essentially, steps were taken to improve the volunteers' internal locus of control to encourage continued participation.

Fortunately, even if a program has lower numbers of participants, a useful volume of data can still be collected due to an interesting phenomenon. Evidently in citizen science programs it's typical for a disproportionate amount of data to be collected by a smaller number of volunteers, and a smaller number of dedicated volunteers is more likely than a larger number of casual participants (Cunha et al., 2017). This pattern is a little contrary to the trend of many people submitting only one report to WISC—and to WISC's hope that many people will casually participate in the reporting program while recreating outdoors. Before the expansion of the IveGot1 program, there were just two very active participants (Falk et al., 2016). Unfortunately, they didn't end up contributing enough snake data to make up for the lack of participation throughout the rest of the program. But it seems that ideally, with enough volunteers that have their own interesting personal reasons for being hardcore contributors, even a program with few participants can still generate useful amounts of data. While IPANE boasts over 900 trained volunteers, 600 of whom are active after ten years (Bois, 2011), a program could still be successful without such numbers if it can attract a dedicated core of volunteers.

Data Quality

General recommendations for protocols and validation were discussed in the section on citizen science in chapter 2. As discussed there, data collected by citizen scientists is generally considered to be of sufficient quality for certain types of uses, like establishing large-scale trends. There are a few steps citizen science programs may take to ensure that the data collected by their volunteers is useful: having well-designed data collection protocols, limiting the range of reportable species to make identification easier, and having some form of data validation in place. Good data collection protocols and a shorter list of reportable species promote better participation as well as better data quality by making it easier to participate. Validating data doesn't necessarily improve the quantity of participants, since validation doesn't impact the participants directly, but it does increase the quality of participation—which is also valuable. Achieving quality participation is important to citizen science, as high levels of participation are not as helpful if the data collected is of poor quality.

As discussed earlier, keeping data collection protocols simple enough for volunteers to handle is important to ensuring success, for complex protocols limit data quality and discourage volunteers. These three programs have a range of data collection protocols.

The Invaders of Texas program encountered some problems with its data collection protocols, having previously required more advanced decision-making and complicated reporting from volunteers. Data collection protocols were later shifted to be easier for volunteers to handle (Gallo & Waitt, 2011). Data collection is currently fairly unstructured, allowing the volunteers to go where they please looking for invasives. But the data itself is fairly detailed, including species, date, GPS coordinates, time spent recording the observation, disturbance type of site, shape of patch, photos attached, and abundance of the species (Texas Invasives, n.d.). These observations would require more thinking, so the program requires all participants to complete the trainings and make an account to submit reports. Previously data were collected on field forms with a borrowed

GPS unit, but now the program has a mobile app that combines these to make data collection simpler.

IveGot1 has protocols similar to the Invaders of Texas, asking people to report whatever they see and using a mobile app to make reporting easy. But IveGot1 doesn't require as much information in the observation report, only a species, quantity of individuals, image, GPS location, and the time spent making the observation. IveGot1 also requires an account to report, but no training (Ivegot1, 2018).

Of the three, IPANE uses the most rigorous protocols, having volunteers sample entire plots and identify every invasive plant found in each plot, as well as collecting data on soil moisture, light levels, etc. (Bois, 2011). While sampling plots may be a lot more complex than what WISC does in having people simply report whatever they find, it does result in higher quality data due to scientific rigor, and it is made possible by the periodic training events IPANE hosts to teach its volunteers the protocols. IPANE uses a mobile app as well as a website-based reporting system that make submitting all this data fairly easy (IPANE, 2018).

WISC's data collection is the simplest of all these programs. Reporters are asked only to keep an eye out for invasive species, not to go looking for them specifically, much less establish plots to sample. The species, location, photo, description, and contact info are all that are required in the mobile app, and the web form requires even less—only name and email are actually required, while species name, date, description, count, and location are all optional. Neither the app nor reporting form require any training to use nor an account to sign up, making them more easily accessible but possibly also sacrificing the quality of the reports (Washington Invasive, 2009).

Limiting the range of species volunteers are asked to look for is another way monitoring programs increase the quality of the data. New species of plants, insects, and other animals can be a challenge for people to learn to identify. Invaders of Texas focuses only on easier-to-identify species when training its volunteers so as to not overwhelm them with new information during its one-day training sessions (Gallo & Waitt, 2011). Texas is a large state with many different ecosystem types, so Invaders of Texas breaks up the state into 10 distinct ecoregions and promotes the dozen most worrisome terrestrial invasive plants in each of these ecoregions (Texas Invasives, n.d.). IveGot1 and IPANE don't limit the reportable species much; IveGot1 has 68 animals and 138 plants (IveGot1, 2018), while IPANE has 111 plants (IPANE, 2018).

While the reportable species on WISC's list are not all necessarily easy to identify, they were selected with the harm done by the species in mind, not how easy it would be for citizen scientists to monitor them. This reflects the intention of the list to represent funding and management priorities, not the needs of the monitoring program. Still, WISC does cap the priority list at 50, greatly limiting the range of reportable species of the hundreds of invasive species present in Washington. WISC doesn't distinguish between invasive species in different ecoregions in Washington but, given the dramatic ecological differences between the eastern and western portions of the state, perhaps such distinctions could help further limit the numbers of species people would be presented with.

All three of these other monitoring programs do some level of data validation. Validating data generally involves staff members verifying that a species was identified accurately by the citizen scientist, often with an attached photo of the species. The

IveGot1 program automatically marks all reports as “unverified” until a staff member can verify it using the attached photos (Wallace et al., 2016), and the Invaders of Texas program requires a digital photo to be submitted with a report for verification purposes (Gallo & Waitt, 2011). IPANE only requires certain species—the more difficult-to-identify ones—to have a specimen collected or a photo taken for later identification by staff (Bois, 2011). Washington's program doesn't require a photo attachment, but they are strongly encouraged, and WISC often does receive them. Every photo received is used to verify whether an invasive species was correctly identified, though for those reports that don't include photos, no such verification can be made.

Conclusion

These monitoring programs differ in some key ways. The three other programs are more active about recruiting volunteers, with IPANE and Invaders of Texas offering trainings, while WISC doesn't have true volunteers at all, though it has recently been offering some trainings. Programs like master naturalists could offer a pool of participants, but perhaps fewer than expected if the trainings can be used as credits for the program. However, even a small number of active participants can bring in valuable amounts of data, though WISC's aim is to get more passive, casual participation than any of these other programs were looking for.

Including a limited range of reportable species can help volunteers make accurate IDs, but it's important to include in that range commonly found species so that volunteers don't get discouraged by being unable to find anything to report.

Data validation to improve data quality can be done by having staff check photos of each species reported, and by flagging species reported outside their usual areas—

things WISC doesn't stringently do, though some reports have photos and these are checked but not marked as accurate or inaccurate. Data quality can also be improved by simplifying the data collection protocols, though more complex protocols like those used by IPANE allow for more types of information to be collected.

While these comparative case studies suggest some ways in which WISC could improve to become more successful, these changes may not be a good choice if WISC is aiming for a different, less structured and more casual sort of citizen science program.

WISC's program right now is mostly an open-to-everyone reporting form and app, with some outreach methods that may be linked to participation in the reporting program. Starting in the next chapter, the remainder of this thesis will focus solely on WISC’s monitoring program in order to provide insights on how agencies can improve their citizen science programs as a method of monitoring invasive species. The following chapter presents the methods this research project used to answer the research questions, “How are reporters of invasive species sightings learning about invasive species and the reporting program, and how familiar are they with WISC’s slogans?”

Chapter 4: Methods

This study was conducted with the goal of discovering whether WISC's core outreach initiatives and its methods of outreach had any correlations with participation in its reporting program, in order to look for ways to improve this citizen science program for monitoring invasive species. The methods consisted of an online survey of a sample of participants who had previously submitted an invasive species sighting report to WISC, asking them about their experience and what led them to report the invasive species. The survey questions were designed to determine how reporters of invasive species were learning about invasive species and the reporting program, and how familiar they were with WISC's slogans. The questions were shaped by the decision to collect data via survey versus interviews or other methods, for it would allow the collection and analysis of greater volumes of data. For simplicity's sake the survey asked about subjects that were easy to categorize, like the sources of people's information. The survey sample was selected purposively from the archives of past invasive species reports, eliminating reports that were ineligible for various reasons. Data analysis was straightforward, consisting of only presenting the percentages of answers given, comparing the answers given to species reported, and comparing the number of reports per county to the population from each county. Because the survey largely consisted of yes/no questions, more complicated statistical analysis would not have been appropriate.

Gathering Past Reports

First, all records of past invasive species reports were acquired. Reports through the mobile app "WA Invasives" were excluded because they do not include an email address, so reporters would have been more difficult if not impossible to contact. Two types of records of past reports submitted through the web form were available: an Excel spreadsheet covering 2009 to early 2013, and a series of organized folders collecting ".msg" file copies of email reports from mid-2016 through all of 2017. The fate of reports between September 2013 and the end of 2015 is unknown; likely they were never recorded in any fashion. These reports were not recorded consistently due to changes in staff responsible for the record-keeping. Not all reports included photos, and whether a species was accurately identified in the report was sometimes recorded in the Excel spreadsheet records, but never the email records.

A simple spreadsheet was created to copy relevant variables from the reports including: email addresses; species reported; county of sighting location; and whether the species reported was accurately identified. Names of species were standardized (e.g., Scotchbroom was changed to Scotch broom *[Cytisus scoparius]*) and certain species were put into the same category according to WISC's categories of priority species, such as how all species of invasive crayfish are considered as one.

Purposive Sampling

The sample was chosen purposively from these records, with some discretion. There were 713 records in the archives but only 482 were eligible to be surveyed. Given that the survey specifically asks about the reporting form, reporters who sent an email report without using the reporting form were excluded. Some individuals also reported an unknown species—that is, they sent a description and photo of something they weren't sure about—while others reported a species that turned out to be native, not invasive. Given that the survey asks them how they learned that their reported species was invasive and how they identified it, these reports were also excluded. Reports from outside Washington were not eligible either.

The survey sample is comprised only of those people who chose to respond to the survey. While it is not ideal to have a self-selected sample, no obvious bias was evident as a result.

WISC is housed within the state government agency, the Recreation and Conservation Office (RCO). Permission was gained from the RCO to both use an RCO email address and the agency's SurveyMonkey account, since the results of this research are pertinent to WISC. While the agency facilitated this research by allowing the use of these official venues, the design and implementation of this research were otherwise conducted independently of the agency. The choice to use these agency venues was made hoping they might make the survey appear more official and thus encourage responses. After the list of email addresses was successfully copied over from the reports into the spreadsheet, an email with a link to the survey was sent from a "@rco.wa.gov" email address. This email thanked the reporters for their prior report and explained that they were receiving an invitation to complete this survey as part of a graduate thesis research project. The invitation agreed to keep all responses confidential and only report on trends. Participants were told that their survey responses were valuable data for improving WISC's public engagement efforts to get more data on invasive species. A copy of this completed thesis was offered to those interested.

The Survey

The survey was designed with the assistance of the Executive Coordinator of WISC, Justin Bush, and it was reviewed by the Washington Invasive Species Council

Chair, Ray Willard, and by Edward Whitesell, Member of the Faculty at The Evergreen State College.

The survey was hosted on the website SurveyMonkey on an account belonging to the RCO. There were seven questions in the survey, though only three of them were really important to this research. The survey questions were:

- *1. Please agree to these terms before continuing.*

In the SurveyMonkey form, prior to the actual questions was the informed consent agreement. This question contained a single possible answer, a checkbox reading “I agree,” and the question was unable to be skipped, in order to ensure that nobody skipped the question and thus rendered their answers unusable.

- *2. Your email address (In order to connect your survey responses to your original invasive species report, please input the same address this survey was sent to):*

This question was necessary because, short of generating a unique link to the survey page for every email address, there would have been no way of knowing which reporter gave which answers. Since their email addresses were attached to the report, this question was for identification purposes only, allowing the comparison of their prior report to their answers to this survey. This was also a mandatory-response question.

- *3. How did you identify the invasive species that you reported? Select all that apply.*
    - *I looked it up on a WISC web page*
    - *I looked it up on another webpage (please specify)*
    - *I looked it up in printed material (please specify)*
    - *I saw it on WISC's Twitter*

- *I saw it on WISC's Instagram*
- *I saw it on WISC's Facebook*
- *I saw it on social media reposted from another source (please specify)*
- *I saw it in a news article or TV program (please specify)*
- *I learned about it from a WISC representative at an outreach event (please specify)*
- *I don't remember*

This is the first question of importance to this research. Also provided was an open-answer comment box for people to elaborate or provide other answers.

- *4. How did you learn about WISC's invasive species reporting form? Select all that apply.*
  - *Social media (Facebook, Instagram, etc.)*
  - *Word of mouth*
  - *Google or other search engine (please specify what you were searching for)*
  - *Linked to it from another website (please specify other website)*
  - *Learned about it from WISC representative at outreach event (please specify event)*
  - *I don't remember*

The second core question, also followed by an open-ended comment box.

- *5. Which outreach initiatives have you heard of? Select all that apply.*
  - *Don't Let It Loose*

- *Don't Move Firewood*
- *Squeal On Pigs*
- *Clean Drain Dry*
- *Play Clean Go*

The final important question for research purposes.

- 6. *Did someone from WISC follow up with you after your report, and did you feel you got all the information you needed?*
    - *Yes, someone followed up and I got all the information I needed.*
    - *Yes, someone followed up but I wanted more information.*
    - *No, someone from WISC or another agency did not follow up.*

This question was not driven by research needs, but was added in at the request of WISC for their own purposes. Typically a representative from WISC will either respond directly to each email report with more information about the invasive species, or refer the report to an expert at another agency to follow up.

- 7. *Any other comments you would like to share with us about what led you to report this invasive species to WISC?*

Based on lessons learned from a prior survey designed for a WISC outreach project, it seemed a good idea to leave a general comment box for respondents to share any comments they thought worthwhile. This was later refined into asking about why they made the invasive species sighting report, in order to help guide their answers into something that might be helpful to WISC. This question was chosen instead of a direct question about personal motivations for reporting, as few responses were anticipated if the question was too open-ended. Offering check-box answers might have run the risk of introducing bias, as one of the options would have been something like "environmental concern," something that people may have chosen because it sounded good, not because it was necessarily true.

Data Analysis

In order to compare how survey responses varied with the species reported, it was necessary to determine the most commonly reported species—those species that had enough reports and survey responses to statistically analyze. Any species with more than 10 reports were distinguished as a top-reported species. The response rates for the answer options for each question were presented as-is, then the answers from reporters of top-reported species were compared by which species was reported, to determine whether there is any relationship between species reported and familiarity with outreach slogans/methods. Finally the percentage of reports from each county was compared to the percentage of Washington's population living in each county, to look for any discrepancies that might indicated a lack of awareness of WISC's reporting program. Discrepancies could reflect disproportionate amounts of outreach conducted in different parts of the state, something WISC may want to know to direct its outreach efforts in the future. The population of each county is taken from a 2017 population estimate provided by the Forecasting and Research Division of the Washington State agency, the Office of Financial Management.

Conclusion

This survey was designed to be a straightforward process pf survey data gathering and analysis, in order to accommodate the large body of invasive species reporters being contacted. The main information being sought is how reporters are finding out about invasive species and WISC's reporting form, and which outreach initiatives reporters were aware of. A few correlations were also sought, like whether the species reported was correlated to how the respondent found out about the species and reporting form, which outreach initiatives they may be familiar with., and how volumes and proportions of reporting varied by county. The findings are presented and explained in the following chapter.

Chapter 5: Results

WISC's reporting system, like many others, attempts to capitalize on citizen science as a tool to help Washington State agencies monitor invasive species. The results primarily answer the research question about reporterss sources of information and knowledge of outreach slogans, but also contained some surprising extra information. The results of the survey demonstrate a few ways in which ideas from environmental education and science communication have been important to WISC's reporting system and could continue to be used to improve the program.

Science communication advocates the use of the internet in reaching the public about science, and these results show that the internet did play a large role in teaching reporters about invasive species and encouraging participation in the reporting system. Most reporters' knowledge sources were either WISC web pages or other web pages. Sources of information did not vary much with the species reported, except for two species where social media was an unusually high source of information likely due to two social media posts from WISC, each highlighting one of the species. So though WISC has a fairly small social media reach overall with only 1,779 followers across Facebook, Twitter, and Instagram combined as of May 2018, posts on specific species do have the power to get more people to report those species. The reporters also expressed a great deal of environmental concern in their reasoning for making the report—something that WISC should continue to capitalize on to encourage more participation in the future.

There were a few discrepancies between the populations of each county and the number of reports received from each county, but most counties demonstrated proportionate numbers of reports.

Species Reports Numbers

Appendix A shows the total number of reports for every reported species taken into consideration from the 482 reports from Washington State that were included in this study. Since there were 116 different species reported, and since most species had less than three reports, anything with more than 10 reports was separated out as a top-reported species. These top-reported species were: nutria (84); bullfrog (78); Asian or citrus longhorned beetles (72); brown marmorated stink bug (33); Japanese knotweed (13) and Scotch broom (13) (see Figure 5 for a comparison of reports received and Figure 6 for images of the species).

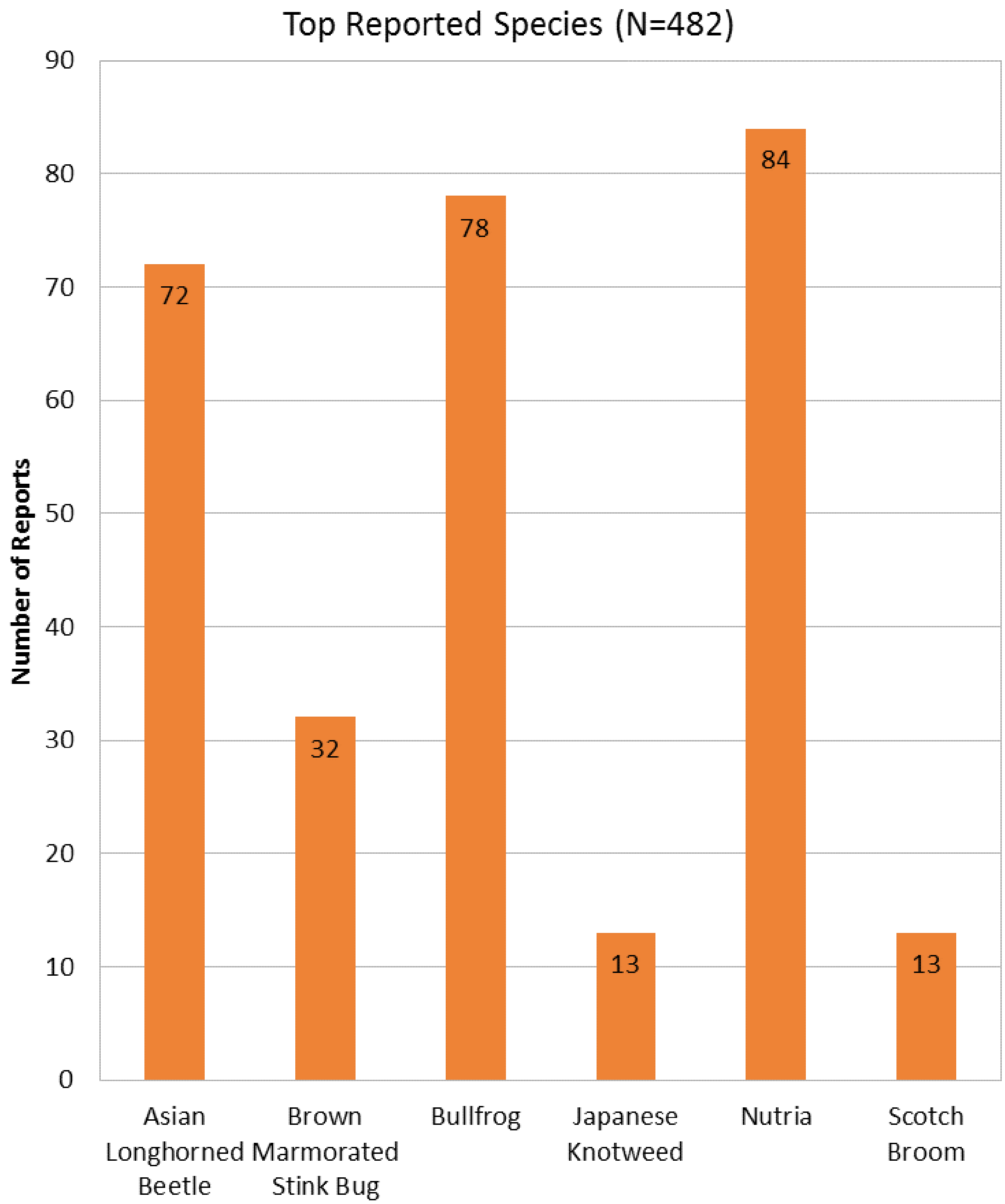

Figure 5. Comparison of the number of reports of top-reported species.

Figure 6. The six top-reported species.

Despite WISC having only 50 priority invasive species for which it promotes education, more than twice that number of species were reported. This indicates that people are not primarily learning about the invasive species through WISC first—which is supported by some of the comments people left. Comments from 12 survey respondents indicated that people saw the species and then found out it was invasive and attempted to look up what to do with it, rather than finding out about it through WISC and then finding and reporting it.

How People Found Out About the Species They Reported

Below are the survey responses for the reporters' sources of information about the invasive species they reported. This question allowed for multiple answers given per person.

Table 1

Sources of Information for Invasive Species Reported

Species info source	# responses	% responses
WISC webpage	64	32.49
Other webpage	59	29.95
WISC outreach event	2	1.02
WISC Twitter	0	0.00
WISC Instagram	1	0.51
WISC Facebook	4	2.03
Social media repost	9	4.57
Printed media	16	8.12
News/TV program	16	8.12
"I don't remember"	24	12.18
# comments	125	63.45

Table 1 presents the results from the survey question, "*How did you identify the invasive species that you reported?*" WISC web pages or other webpages were the most common information source on the invasive species reported, with roughly a third of respondents answering with either option. Social media did not play a huge role, and WISC social media played less of a role than reposted content from other social media pages. This reflects the currently small reach of WISC posts, reaching an audience of just 1,779 followers across all its social media platforms combined as of May 2018. The comments offered some reasons for these results. Comments from 18 survey respondents described seeing an unknown species and conducting an internet search to find out what it was. Comments from 48 survey respondents stated that they already knew of the species before they saw it, sometimes from friends, from work, from school, or from articles they'd read in the past. Three respondents commented that they just took a picture and sent it in without ever really knowing what species they were reporting.

Table 2

Sources of Information for Reporting Form

Reporting form info source	# responses	% responses
Search engine	105	53.30
Word of mouth	19	9.64
Social media	17	8.63
Link from another webpage	10	5.08
WISC outreach event	6	3.05
"I don't remember"	37	18.78
# comments	96	48.73

Table 2 presents the results for the question "*How did you learn about WISC's invasive species reporting form?*" Just over half of all respondents found WISC's reporting form through a search engine. Comments reveal that 11 reporters, after realizing that what they'd seen was an invasive species, already wanted to find a way to report it. According to the explanatory comments left, 21 respondents, when trying to find a place to report the species, searched for combinations of terms like "invasive species," "Washington," and "report." Seven reporters specifically mentioned being referred to WISC's reporting form via the Washington Department of Fish and Wildlife's page, while others found WISC's website and reporting form directly through a search engine. Other sources of information each represented less than 10% of the answers given.

Outreach Slogan Familiarity

The slogans from the survey represent outreach initiatives adopted by WISC. WISC's website has pages for Don't Move Firewood, Don't Let It Loose, and Squeal On Pigs (see Figure 7 below), but not for the other campaigns.

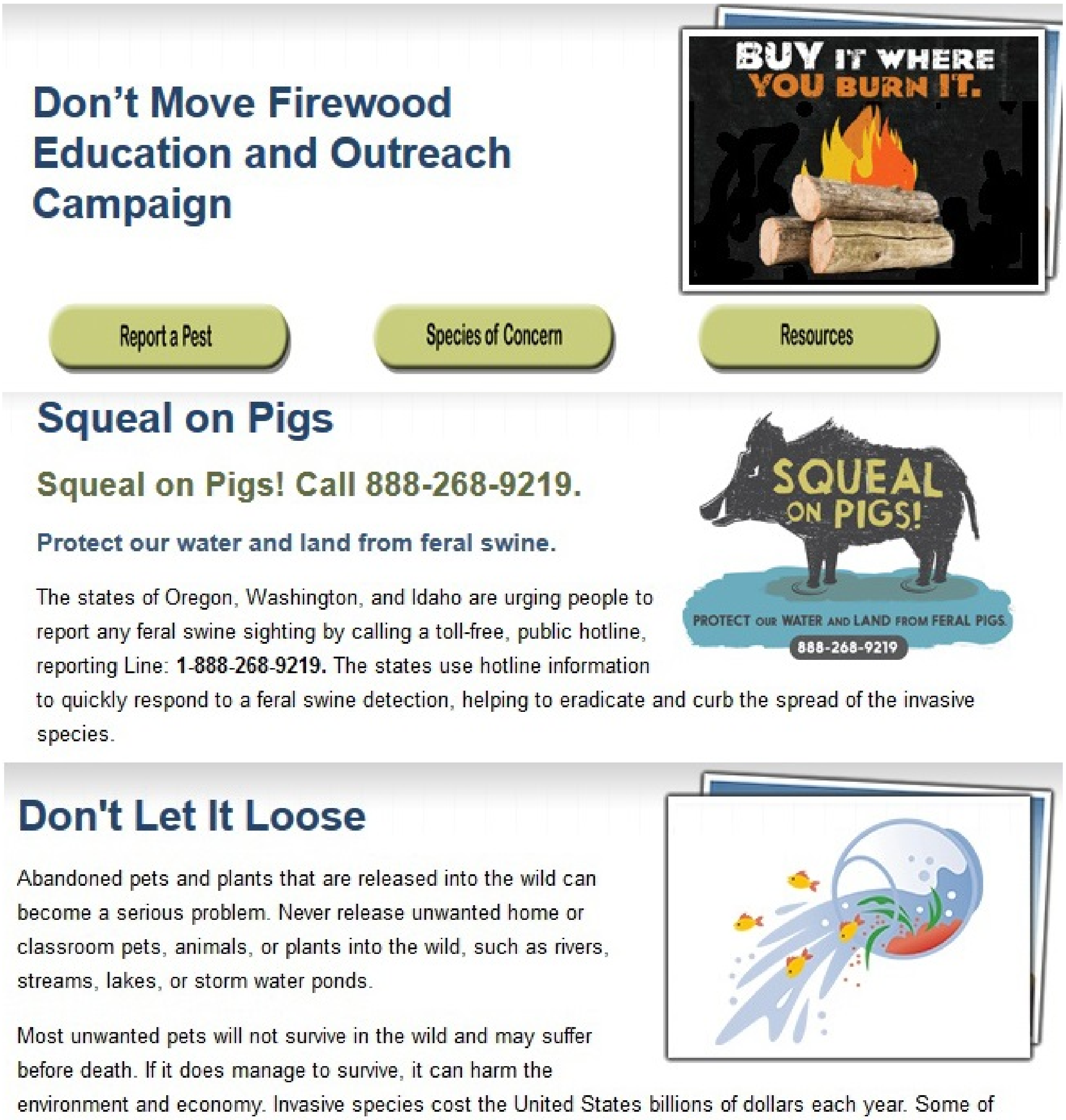

Figure 7. Screencaps of WISC's web pages promoting its outreach campaigns.

Don't Let It Loose has also been promoted at events like the SeaTac Pet Con and through stickers. WISC has pamphlets and stickers promoting Don't Move Firewood that are distributed at invasive species workshops. Squeal On Pigs is represented through a feral swine open house hosted in winter of 2018, and stickers passed out at workshops.

The Washington Department of Fish and Wildlife, an agency with representation in WISC, has a page on its website for Clean Drain Dry and sometimes partners with WISC to send representatives to promote the slogan at outreach events such as the Seattle Boat Show and Pacific Marine Expo.

Though WISC considers Play Clean Go one of its adopted slogans, it doesn't have outreach efforts associated with it other than free boot brushes that were passed out at invasive species workshops to professionals in the field.

Table 3

Familiarity with Outreach Initiatives

Slogan	# responses	% responses
Don’t Move Firewood	31	15.74
Don’t Let It Loose	21	10.66
Clean Drain Dry	13	6.60
Play Clean Go	13	6.60
Squeal On Pigs	10	5.08

Table 3 presents responses to the question “*Which outreach initiatives have you heard of?*”Overall, survey respondents were not extremely familiar with WISC’s outreach slogans. Don't Move Firewood is best known, with over 15% of respondents recognizing it, making it two to three times better known than most slogans. Don't Move Firewood is a campaign started by The Nature Conservancy that has been adopted by other states in addition to Washington which may contribute to how well known it is. Don't Let It Loose was the next most-known slogan with over 10% of respondents having heard of it, while the other slogans ranged from about 5–7% in familiarity. The lack of familiarity with Play Clean Go is not surprising given how little WISC does to promote it, but Clean Drain Dry is surprisingly unknown considering that WDFW also promotes the campaign with signs and through its presence at multiple boating-related outreach events. The feral swine webinar and printing of the Squeal On Pigs stickers happened in 2018, so perhaps future reporters will demonstrate more familiarity with this slogan.

Top-Reported Species Compared to Survey Responses

The top-reported species were compared to their reporters' survey responses to determine whether the survey responses varied with the species reported. But only those top-reported species that were reported by at least 10 survey respondents are considered here—thus Japanese knotweed (*Fallopia japonica*) and Scotch broom (*Cytisus scoparius*) are excluded from the following survey response analysis, as only seven and five respondents reported these species, respectively.

For Asian longhorned beetles (ALB, *Anoplophora glabripennis*), 31 respondents reported them; for brown marmorated stink bugs (BMSB, *Halyomorpha halys*) 18 respondents reported them; for bullfrog *(Lithobates catesbeianus)* 31; nutria *(Myocastor coypu)* 36. Tables 4, 5, and 6 below present the percentages of survey responses from people who reported each of these species.

Table 4

Species Reported Versus Information Source for Species

Species info source	ALB%	BMSB%	Bullfrog%	Nutria%
WISC webpage	29.03	0.39	0.39	0.42
Other webpage	29.03	0.50	0.48	0.28
WISC outreach event	0.00	0.00	0.00	0.00
WISC Twitter	0.00	0.00	0.00	0.00
WISC Instagram	0.00	0.06	0.00	0.00
WISC Facebook	6.45	0.11	0.00	0.00
Social media repost	6.45	0.11	0.03	0.00
Printed media	6.45	0.06	0.03	0.03
News/TV program	19.35	0.00	0.03	0.11
"I don't remember"	12.90	0.28	0.00	0.11
# comments	67.74	0.50	0.61	0.56

Note. "ALB" refers to Asian/citrus longhorned beetles and "BMSB" refers to brown marmorated stinkbugs.

Table 4 compares the top-reported species to the source of information for the species. These results more or less reflect the results of all reported species—similar numbers of people were finding out about the species from either a WISC web page or another webpage, very few from social media, and a few from other sources. Given the small sample sizes, some variation is expected. Note that many respondents were unable to remember how they learned about bullfrogs. Comments indicated that many people are familiar with bullfrogs from repeated exposure, sometimes in other parts of the country where bullfrogs are even more widespread. Note the slightly higher rates of social media as an information source on Asian longhorned beetles and brown marmorated stink bugs—this result is also reflected in the following table and will be explained in the next section.

Table 5

Species Reported Versus Information Source for Reporting Form

Report info source	ALB%	BMSB%	Bullfrog%	Nutria%
Social media	16.13	38.89	3.23	5.56
Word of mouth	9.68	16.67	12.90	5.56
Google	51.61	38.89	58.06	63.89
Link from other page	0.00	5.56	6.45	8.33
WISC outreach event	0.00	0.00	3.23	0.00
"I don't remember"	16.13	5.56	22.58	13.89
# comments	32.26	33.33	41.94	55.56

Table 5 compares the top-reported species to the source of information for WISC's reporting form. These results are also mostly in line with the general results, with most people finding the reporting form through a search engine.

However, for both the reporting form and species knowledge source, surprisingly higher numbers of people reporting Asian longhorned beetles and brown marmorated stink bugs reported social media as their information source. This may be due to some social media posts made by WISC in 2017 featuring brown marmorated stinkbugs, which were followed by reports of these species. The somewhat higher rate of Asian longhorned beetle reporters finding the reporting form through social media may also be due to some social media posts and a corresponding WISC press release from August 2017 highlighting wood-boring pests like longhorned beetles. Although social media had an overall lower impact than other information sources, it seems that posts on these species did have some detectible effect.

Table 6

Species Reported Versus Familiarity with Slogans

Slogan	ALB%	BMSB%	Bullfrog%	Nutria%
Don't Let It Loose	6.45	5.56	12.90	11.11
Don't Move Firewood	9.68	16.67	12.90	11.11
Squeal On Pigs	0.00	0.00	3.23	2.78
Clean Drain Dry	3.23	5.56	6.45	2.78
Play Clean Go	0.00	11.11	6.45	8.33

Table 6 compares the top-reported species to the percent of their reporters with knowledge of outreach slogans. These results reflect the general findings, with Don't Move Firewood being the best-known slogan, followed by Don't Let It Loose, with the others being lesser known. There are no unusual correlations that stand out, but the slogans were so poorly known among the reporters of these species that few conclusions can be drawn from these results.

Spatial Analysis

As shown in Appendices B and C, Western Washington represents a higher density of invasive species reports, with 422 reports compared to Eastern Washington's 59 reports. King County along had 145 reports originating there. Western Washington had nine counties with at least 10 reports, while only one county—Wahkiakum—had no reports. In contrast, eastern Washington had only one county with more than 10 reports, and four counties with no reports.

Since so many counties had very few reports and even fewer survey respondents, comparing the survey results to location would not have been meaningful. But it was possible to compare the percentage of reports coming from each county to the percentage of the state's population living in that county, in order to determine whether there were major discrepancies. Figure 8 below compares these two variables.

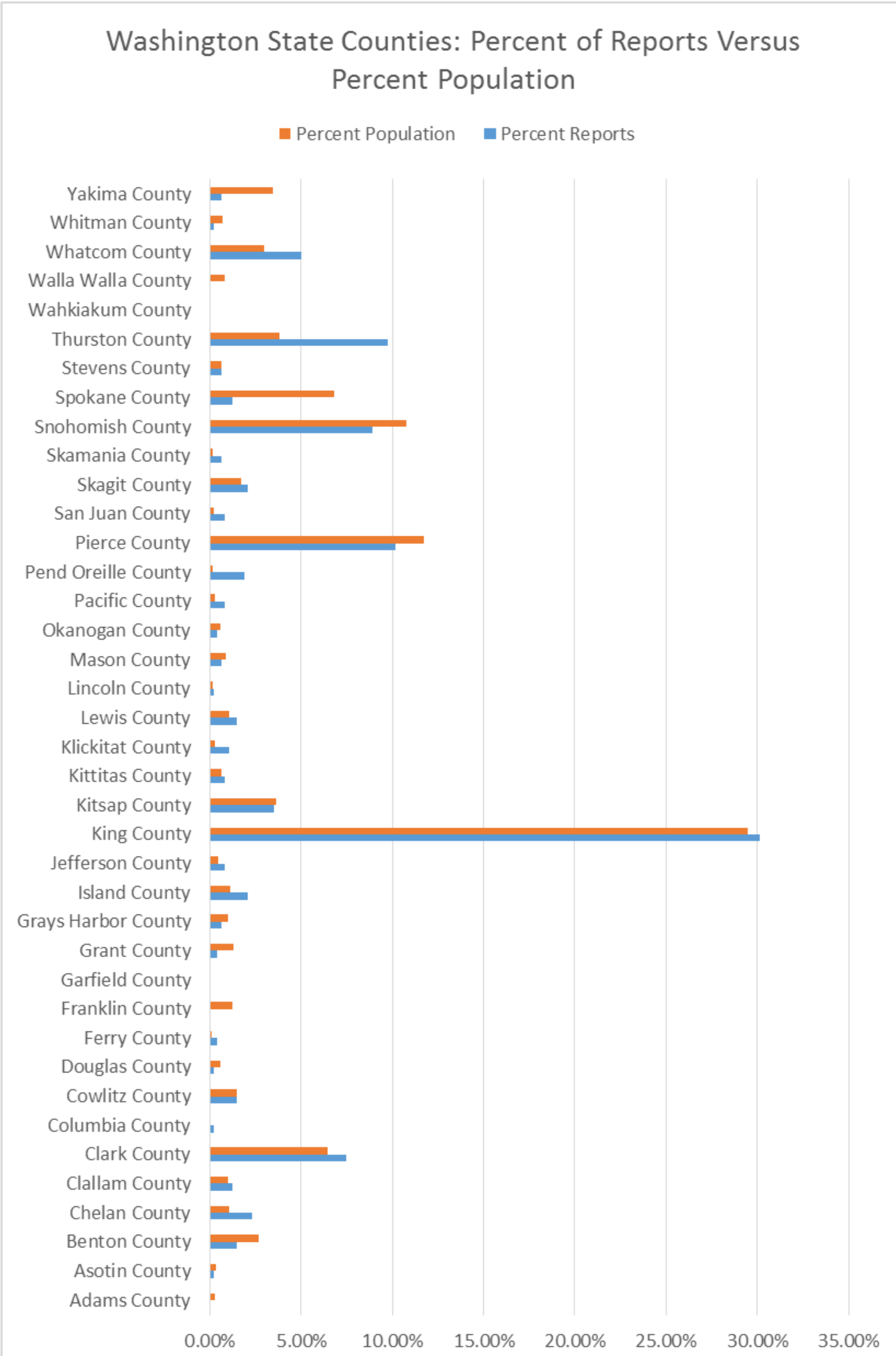

Figure 8. County populations versus reports. This graph compares the percentage of the invasive species sighting reports coming from each county and the percentage of Washington State's population living in that county.

For the most part, the population in each county correlates fairly well to the number of reports coming from that county. Note that there are a few larger discrepancies: Spokane County had strikingly few reports relative to its population, and Thurston County had a surprisingly high number of reports relative to its population. The outsized number of reports from Thurston County may be due to the influence of the many public agency employees located around the state capital, Olympia. The reason for the lack of reports from Spokane County is unknown. Geographic differences in the levels of public education and outreach conducted by WISC between counties might explain the differences—WISC may be able to conduct more in-person outreach in Thurston County because that is where WISC staff is located, for example. Increasing the number of outreach events in under-represented counties may help improve the participation rates there.

Misidentified Species

One interesting finding of this study was that there were 17 reports of Asian/citrus longhorned beetles (*Anoplophora* spp.) that included photos, and all 17 reports were inaccurate, as the photos clearly depicted other species of insects. Asian/citrus longhorned beetles were reported 72 times total. The other 55 reports without photos remain unverified because, as of May 2018, there is no confirmation that these beetles are established anywhere in Washington. The only other known inaccurate reports were: a single report of English holly (*Ilex aquifolium*) that was actually Oregon grape (*Mahonia spp.*), and one report of a nutria (*Myocastor coypu*) that appeared to be a muskrat (*Ondatra zibethicus*, another aquatic rodent, but it is native to the area). Some of the incorrect reports of Asian/citrus longhorned beetles were actually the native banded alder borers *(Rosalia funebris)* or white-spotted sawyers *(Monochamus scutellatus)*. All three are closely related longhorned beetles with similar black and white coloration. As shown in Figure 9, the white-spotted sawyer is particularly similar-looking, distinguishable mainly by the slight difference in its white spots and the rougher texture of its wing covers.

Figure 9. Comparison of native and invasive longhorned beetles. On the left is the native white-spotted sawyer; photo courtesy of Joseph Berger, Bugwood.org. On the right is the invasive Asian longhorned beetle; photo courtesy of Washington Invasive Species Council.

The Open-Ended Comment Box

The final survey question asking reporters if they had any other comments about what led them to make a report functionally took the place of a more direct question about motivation, since 43 people took the opportunity to mention their motivations.

There were 112 people who left comments, 24 of whom expressed positive sentiments—they were happy someone was using their report, happy to try to help protect the natural environment from harmful invasive species, and happy that WISC exists. But

11 respondents had less positive sentiments to express. Several individuals felt disappointed with the response to their report, feeling that reporting it had been a waste of time. Many respondents (45) never got a response to their report at all. One reporter who was invited to participate in the survey refused to do so, stating that WISC didn't do enough to help after this reported had contacted WISC about an invasive species.

Limitations

The invasive species report archives dated back to 2009, meaning that roughly a third of those individuals contacted for the survey had filed the report prior to 2016. At least 14 reporters invited to participate in the survey did not remember what they had reported, based on the emails received explaining so. Possibly even more couldn’t remember but said nothing. Wherever possible, these individuals were given details of their past report to jog their memories so they could more accurately fill out the survey. Comments from four survey respondents indicated that the respondent filled it out without remembering what they had reported, and it is possible many more reporters both could not remember and may have been discouraged from filling out the survey. This means there may well be a bias towards more recent reports in the survey results, but since date of report was not a variable considered in this study, it is impossible to say. A reminder in the invitation email of what species the reporter reported may have helped address this issue.

Given the comments indicating that the reporter learned about the invasive species through their job or through school, this would have been a good option to present in the appropriate survey question.

In the survey question about familiarity with outreach slogans, a “none of the above” option should have been included to distinguish between lack of familiarity with the slogans and respondents who skipped the question for other reasons. One comment revealed that the respondent was under the impression that no questions were skippable, so this may have affected the results if other respondents were under the same impression and picked a random answer. It also would have been useful to ask how the respondent encountered each slogan, just for the sake of learning more about how WISC's outreach efforts are reaching people. But, without knowing how well-known WISC's outreach initiatives are among people who haven't submitted an invasive species reports, it's impossible to say whether there are any differences in familiarity levels between reporters and non-reporters, or whether familiarity with particular slogans correlates to likelihood to make an invasive species report. And no causal relationships can be inferred between familiarity with the slogans and participation in the reporting system, since it is unknown whether respondents encountered the slogan first or the reporting system first.

Although it was possible to note a few reports with misidentified species, without better records of invasive species reports that include photos or other confirmation of the species ID, accuracy of the reports is not a variable that can be analyzed.

Conclusion

The internet played a significant role in informing reporters about the invasive species they reported and about WISC's reporting form. Search engines helped people find WISC's web pages when they wanted more information or wanted to find somewhere to report the invasive species and, though WISC's social media generally had little correlation to reporting, posts on specific species did have the power to increase the number of reports of those species. WISC's outreach initiatives were overall not known very well by reporters and no conclusions could be drawn about the relationship between familiarity with these initiatives and likelihood to report an invasive species. Though species ID accuracy was not a variable that could be analyzed due to the lack of data available, a noteworthy 17 cases of misidentified Asian longhorned beetle were noted in the reports. While most counties had a number of reports proportionate to their populations, Thurston county was overrepresented and Spokane county was underrepresented. Focusing more outreach efforts in Spokane county may help address this gap. The next chapter will attempt to interpret these findings in the context of the literature and case studies of other citizen science monitoring programs, with the goal of understanding the reasons for these results and how this information can be used to improve outreach and citizen science monitoring programs.

Chapter 6: Discussion

The results of this research, though limited in scope as they mainly pertained to reporter's sources of information and knowledge of WISC's outreach slogans, offered some support for certain recommendations made by the literature. The need for WISC to validate data to increase its quality became evident, as WISC's current lack of validation is hurting the quality and usefulness of its data-set, and improving outreach and the size of the dataset won't be useful until the data quality improves. Models of environmental knowledge, attitude, and behavior explain some of the results, though the results are too narrow in focus to relate to some of the more detailed models. WISC is already using the internet for providing information, which the results suggest is a good idea, but more information would be needed to analyze the effectiveness of WISC's communications efforts at appealing to the public. Following these recommendations will help to improve the ability of citizen science programs to help agencies monitor invasive species.

Citizen Science

One of the primary advantages of citizen science for collecting data is the cost savings associated with employing a smaller number of staff while a large volume of data can be collected by unpaid citizen scientists (Bois et al., 2011). But the small amount of staff within WISC is a limitation that prevents the data collected by the program from being more useful. Only one staff member is available to respond to and record the reports submitted, and the time available to do these tasks is very limited. As a result, the reports received through the web form are not marked validated or not, are not made into species distribution maps, and are not publicly available. False reports are kept together with correct reports and unverified reports without anything marking or distinguishing them, so the archives of reports could not be used to make a map of accurate distributions as they are currently. One of the top-reported species, Asian longhorned beetle (reported 72 times) was confirmed to have been misidentified 17 times—but it is possible that the rest of the reports, which did not include photos, were also misidentified, since this species is not known to be established in Washington. A system for flagging reports as validated/unvalidated and flagging species appearing outside of their known range, as described by Bonney et al. (2009), could greatly improve WISC's dataset by distinguishing between likely misidentified reports and likely accurate reports.

While WISC has collected a large volume of data, not much use is made of it. Invasive species reports are passed on to relevant partner agencies depending on the species type instead of being analyzed collectively and internally. While reports received through the mobile app go to an online map and database that is accessible to the public, reports received through the web form are not mapped or published in any way. The system as it stands currently is able to detect potential new invasions, but does not make full use of the distribution data of species that are already present in Washington. This is partly because reports received through the web form are not published or mapped and partly because of the number of false and unvalidated reports.

Citizen science data are mostly useful for large-scale trends (Bonney et al., 2009), but WISC's dataset may be too small for this right now, with only four species receiving more than 30 reports each between 2009-2013 and 2016-2017. Increasing participation rates in the reporting system might help with this, but a larger volume of data won't be useful unless it is of good quality and made available to be used. Offering training programs as other citizen science programs do may be a way to accomplish this, by improving reporters' species identification skills. WISC has only recently started providing in-person trainings, and has no online modules like the Invaders of Texas program; most past reporters will not have attended any of WISC's trainings because the reports go through the end of 2017 and trainings began being offered in Fall 2017. However, as noted by Crall et al. (2011) and confirmed in my own results, many volunteers have training from outside the program—so the lack of training isn't as big an impediment as it could be because just over 10% of survey respondents commented that they had some experience from work or school.

Because WISC is not organized as a citizen science program to the high degree that other programs are, its priorities are different and these different priorities may always hamper its ability to function as well as other citizen science programs do.

Environmental Education

The goal of this research was not to discover reporters' environmental attitudes, so the questions were not intended for this purpose. Yet, by allowing people to leave comments throughout the survey, a surprising amount of this information was revealed.

Hungerford and Volk's model (1990) seems to apply fairly well to the results of this research. "Ownership variables," which include the knowledge of and a personal investment in environmental issues, and "entry-level variables," like environmental sensitivity, both were reflected in the survey comments. Respondents already understood that invasive species were harmful to the ecosystem, and were concerned by this. Finally, empowerment variables, like an internal locus of control, led people to take action by reporting the invasive species, and a failure in this sense would explain those few who were frustrated after making the report. Feeling like one's actions made no difference was discouraging, and something that WISC and other outreach organizations need to avoid in order to achieve better participation in the future.

The classic model described by Hungerford & Volk (1990), i.e., environmental knowledge —> environmental attitude —> environmental behavior appears to be the implicit assumption of WISC’s operations. Developing education and outreach materials with the goal of changing environmental behaviors is a major focus of WISC, as evidenced by its outreach initiatives that prescribe behaviors like Don’t Move Firewood, Don’t Let It Loose, etc. The findings of this study lend support to this classic model, in the case of WISC. The comments from the survey reflected some degree of environmental knowledge (invasive species are harmful) and a positive environmental attitude (harming the environment is bad)—even though environmental degradation from invasive species can appear less pressing than more immediate threats (Carmi et al., 2015; Kollmuss & Agyeman, 2002). This led to a positive environmental behavior (reporting the species and hoping someone does something about it). But evaluating the outreach material's effectiveness at appealing to environmental emotion or concern is a step WISC could take to make sure it has the greatest effect on changing behavior.

Without a study design more heavily focused on delving into the attitudes and behaviors of reporters, the applicability of some of the more complicated models of behavior will not be possible to consider. However, the model of direct versus indirect experiences (Duerden & Witt, 2010) can be discussed in regards to WISC's education efforts, which mostly take the form of indirect experiences such as presentations, educational brochures, and an informative webpage. Direct, interactive learning experiences are better at educating and engaging an audience. Though this is not something WISC is doing well, it should consider this as a tool to improve outreach in the future.

Science Communication

The literature on science communication criticizes the emphasis on presenting facts without accounting for values and constructing narratives. Though couched in different terms, these are strikingly similar ideas to environmental education's criticism of emphasizing environmental knowledge and neglecting to appeal to environmental attitude or emotion (Carmi et al., 2015; Pooley & O'Connor, 2000). WISC and similar outreach programs would do well to remember this advice. WISC may benefit from reviewing its outreach efforts to ensure that they effectively construct narratives. But the discussion of how difference values create controversy may not apply as well to invasive species—a less controversial subject.

The reporters largely expressed similar environmental values, but without surveying the general public it cannot be said whether reporters harbor more environmental concern than non-reporters. If environmental concern leads to positive environmental behavior, it might follow that reporters would have a greater degree of environmental concern than the general public. But, with a lack of public controversy over invasive species, perhaps the general public does hold similar values about invasive species, and it is only the level of concern that varies.

WISC does some other things well, like using a communications professional to help keep outreach communications understandable for a general audience. But tailoring communications to the audience, as recommended by Hobbs (2006) is not usually possible because much of the outreach material is meant for unspecified or general audiences. WISC also is somewhat able to anticipate information that the public may need (Fischhoff, 2013; Richards et al., 2013). WISC provides information on priority species, which include a mix of the invasive species people are most likely to encounter and the most harmful invasive species. WISC has also done some amount of keeping its information up-to-date as recommended by Richards et al. (2013) by updating its priority list periodically with new concerns. Given that the internet and WISC's webpage played a big role as a source of information for reports, keeping this information available on the internet is also a good step. The popularity of the internet as a source when one wants to learn something specific (Horrigan, 2006) was reflected by the 41 respondents who turned first to a search engine to identify the invasive species they had found and the 105 respondents of people who used an internet search engine to learn how to report the species. However with WISC's social media pages languishing with relatively few followers (1,779 followers total across three platforms as of May 2018), it does appear to be true that other types of media are out-competing WISC for attention due to the huge range of content now available (Nisbet & Scheufele, 2009). But with the social media posts on specific species that cause a noticeable uptick in reports, continuing to build a social media presence and use it to alert the public to species to look for is a strategy WISC should continue to employ.

Conclusion

WISC is doing some things effectively—using a communications professional to make communication clear, and using the internet to reach audiences. Because there is evidence that environmental emotions do impact environmental behavior (reporting invasive species) reflecting on how its communications appeal to emotions and engage audiences may help improve them in the future. Without information on the quality of WISC's outreach efforts, more specific recommendations are not possible. The conclusion will draw from these recommendations for improvement and it will discuss the limitations of this study to suggest further lines of questioning that could aid WISC and other invasive species outreach programs in improving the quality of their outreach.

Chapter 7: Conclusion

Invasive species, due to their ability to reproduce prolifically and thrive in a range of environments, can alter ecosystems by competing for resources and suppressing the populations of native species. Once they become widespread they can become impossible to eradicate completely and endless, ongoing control gets massively expensive. Knowing when a new invasive species first appears is vital to preventing it from taking over. This is where citizen science data become extremely valuable—citizens can detect new invasions, allowing agencies to take action to eradicate the invasion before it becomes too widespread. But even for invasive species that are already well-established, the distribution data provided by citizen scientists can be valuable when trying to leverage more funding for invasive species management. In order to improve the distribution data sets and increase the likelihood of the public detecting a new invasion of a species of concern, agencies managing invasive species need to be able to increase the number of people who know what species to look out for and how to make a report.

WISC needs to use concepts from environmental education and science communication to improve its communication efforts, mimicking the structures of other invasive species reporting programs to the extent possible, in order to help improve the quality of data. The major lessons learned from these research areas are science communication's emphasis on using the internet to connect directly with people, and using narratives to make science more engaging; environmental communication's emphasis on appealing to emotions, and making people feel like their actions make a difference; and the training and validating that improve the data quality of other citizen science programs.

Currently WISC is not effectively validating its data since many reports had no photos, and even those reports with photos proving the report was a false ID were not marked as such, meaning that WISC's report archives cannot be used as distribution data. WISC is beginning to offer invasive species trainings now, which is excellent as this is a major way that other citizen science programs help improve the quality of the data collected to a level appropriate for large-scale analysis.

In regards to the original question about how reporters are learning about invasive species and WISC's reporting form, the answer to both was similar—primarily internet searches. Informational web pages played a huge role in helping reporters identify the invasive species, with a third of reporters saying they used a WISC web page and a third saying they used another web page. WISC's website was easy for reporters to find, which is good but, although the internet does seem to be a powerful tool for education, reporters had to go searching for the information to find it, and few people were learning about invasive species passively by following WISC or other social media pages. Improving the reach of WISC social media pages could be an impactful way to improve invasive species education in Washington and participation in the reporting system by engaging the public directly, given how strong a role the internet is already playing.

Although it was not the primary goal to discover the motivations or attitudes of the reporters, it became clear that many of them had positive feelings about their ability to participate in submitting the report, and were motivated by concern for the environment. These concerns also existed seemingly prior to interacting with WISC in many cases, given that so many individuals found WISC after trying to figure out what to do about the invasive species they saw. Fostering this environmental concern and encouraging invasive species reporting as an action the public can take to help combat the problem of invasive species would be a very effective strategy to encourage more participation in the future.

The few reporters that expressed negative sentiments seemed most upset with what they felt was a lackluster response from WISC. The apparent solution to this kind of dissatisfaction in a citizen science program, then, may be to more accurately represent how their participation is valuable, and what kind of response they can expect after filing a report. This might solve the issue by heading off assumptions of what the response to their report may be, and making it clear that their report is valuable even if the response to it didn't feel significant.

In the course of the research and discussing the results, many potential questions and avenues for further research opened up. Some of these questions were not possible to answer with these research methods, and some simply did not become evident until the results were being interpreted.

For example, many reporters expressed environmental concern—but among the general public, what is the relationship between environmental concern and likeliness to report an invasive species sighting? And how aware of and concerned about invasive species is the general public? Many reporters were already aware that invasive species were bad before coming into contact with WISC, so how is the general public learning about invasive species in general and the issues associated with them?

Too little was discovered about how outreach slogans relate to behavior. Many more questions about these campaigns could be asked, such as in what contexts are people encountering WISC's or other outreach campaign slogans like Don't let It Loose, Clean Drain Dry etc.? How is familiarity with these slogans correlated to the positive environmental behaviors prescribed by these slogans? Cole, Keller, and Garbach (2016) conducted research along these lines for boaters and aquatic invasive species, but this could be expanded to other groups of people, other positive environmental behaviors, and other categories of invasive species.

WISC is actively developing social media as an outreach venue. Though it currently seems to have little impact on reporting invasive species, in the future it would be interesting to analyze how social media posts highlighting certain invasive species correlate with frequency of reports of those species following the posts, compared to reporting activity before the posts are made. This could help WISC better understand the actual impact of their social media posts—and perhaps even allow for comparisons of how language used in the posts correlates to participation in the reporting system.

Although it was not possible to use species ID accuracy as a variable, if such data could be gathered it would be rich with implications for questions to ask about it, such as how confident were reporters about their identification of the species they reported, and how does this confidence correlate with species, location of sighting, source of knowledge, etc.? Knowing this could help WISC and other organizations (a) do more targeted and effective education about proper ID of species that seem to need it the most; (b) target outreach in certain areas; or (c) indicate which forms of outreach are most effective at teaching species ID.

The subject of locus of control is one that could be delved into much more deeply. For example, it could be asked how confident were the citizen reporters that their participation mattered and that their report made a difference. Before conducting this research, nothing was known about motivations for reporting, or reporters' attitudes about their reports. Given how important a sense of internal locus of control is to motivating people to take action, understanding how to improve this sense in reporters is vital to promoting more future participation.

There is little research done on invasive species education and outreach, and many more questions that could be asked and researched on this subject. Although these findings may have some implications for how WISC chooses to conduct outreach in the future, this research only scratches the surface of what remains to be discovered about how to conduct effective invasive species education and outreach.

This research was set apart from the literature in its unique focuses on a citizen science program that has been very loosely organized and has not provided trainings in the past; environmental education efforts that were specifically about invasive species as the subject matter; and communicating science from a government agency's perspective instead of a scientist's. Attempting to find relationships between different environmental education efforts and a citizen science monitoring program also presents a unique subject matter that none of the literature covers—the sources of people's information is not covered at all in the citizen science literature, though it sometimes is by the science communication literature.

Invasive species are a global issue, with many agencies and organizations attempting to manage them for their harmful effects on ecosystems and people. Citizen science is important to supplement these efforts by providing invasive species distribution data that agencies otherwise might not be able to afford—data which can then be used to inform policy and funding decisions for managing invasive species.

Though this research focuses largely on WISC as a case study, the findings of how to improve its outreach and monitoring programs could apply very well to other programs elsewhere in the country or world as needed. Improving invasive species education and outreach will help improve citizen science programs as a tool helping agencies to combat invasive species worldwide.

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Appendix A: Number of Reports for Each Species

Nutria	84
Bullfrog	78
Asian longhorned beetle	72
Brown marmorated stink bug	32
Japanese knotweed	13
Scotch broom	13
Gypsy moth	8
Emerald ash borer	7
Feral swine	7
Butterfly bush	6
European green crab	6
Milfoil	6
New Zealand mud snail	6
Asian clam	5
Mediterranean snail	5
Wood-boring beetle	5
Crayfish	4
English ivy	4
Giant hogweed	4
Hawkweed	4
Blackberry	3
Brazilian elodea	3
Catfish	3
Kissing bug	3
Tansy ragwort	3
Asian carp	2
Bryozoan	2
Chinese mystery snail	2
Didymo	2
Herb robert	2
Scarlet lily beetle	2
Tenlined june beetle	2
Yellow archangel	2
African beetle	1
African clawed frog	1
Atlantic salmon	1
Banded alder borer	1
Bark-boring moth	1
Black locust	1
California prionus beetle	1
Callery pear	1
Camel spider	1

Cane toad	1
Carp	1
Cherry bark tortrix	1
Cimbex luteus	1
Clam	1
Clearwing sycamore beetle	1
Common carp	1
Common crupina	1
Cottonwood borer	1
Craspedacusta sowerbyi	1
Devils coach beetle	1
Eastern gray squirrel	1
English holly	1
Ergates spiculatus	1
European chafer	1
European crane fly	1
Exotic marine mussels	1
False indigo	1
Sculpin	1
Tench	1
Flat-headed pine heartwood	1
Garlic mustard	1
Gizzard shad	1
Golden buprestid beetle	1
Goldfish	1
Grass carp	1
Greater horntail woodwasp	1
Grovesnail	1
Hammerhead worm	1
Harlequin bug	1
Hydrilla	1
Japanese tree frog	1
Koi	1
Kudzu	1
Lamium	1
Lime hawk-moth	1
Longnose sucker	1
Metallic wood borer	1
Milkweed beetle	1
Northern snakehead	1
Persicaria perfoliata	1
Pikeminnow	1
Ponderous borer	1
Poplar borer beetle	1
Prickly sculpin	1

Puncture vine	1
Purple varnish clam	1
Red-headed ash borer	1
Ring-neck turtle dove	1
Rove beetle	1
Rush skeletonweed	1
Russian olive tree	1
Shellfish	1
Sipyloidea sipylus	1
Snapping turtle	1
Snow crab	1
Soft-shelled turtles	1
Spotted knapweed	1
Sturgeon	1
Sydney black funnel web spider	1
Tarantula hawk	1
Tent caterpillars	1
Titan beetle	1
Tunicate	1
Unidentified parasitic worm	1
Vietnamese bamboo	1
Walleye pike	1
Water chestnut	1
Water lily	1
Watercress	1
Whirling disease	1
White lined junebug	1
Yellow flag iris	1

Appendix B: Reports Compared to Population per County

County	# Reports	% Reports	2017 Population Estimate	2017 % Pop. Estimate
Adams County	0	0.00%	19870	0.27%
Asotin County	1	0.21%	22290	0.30%
Benton County	7	1.46%	193500	2.65%
Chelan County	11	2.29%	76830	1.05%
Clallam County	6	1.25%	74240	1.02%
Clark County	36	7.48%	471000	6.44%
Columbia County	1	0.21%	4100	0.06%
Cowlitz County	7	1.46%	105900	1.45%
Douglas County	1	0.21%	41420	0.57%
Ferry County	2	0.42%	7740	0.11%
Franklin County	0	0.00%	90330	1.24%
Garfield County	0	0.00%	2200	0.03%
Grant County	2	0.42%	95630	1.31%
Grays Harbor County	3	0.62%	72970	1.00%
Island County	10	2.08%	82790	1.13%
Jefferson County	4	0.83%	31360	0.43%
King County	145	30.15%	2153700	29.46%
Kitsap County	17	3.53%	264300	3.62%
Kittitas County	4	0.83%	44730	0.61%
Klickitat County	5	1.04%	21660	0.30%
Lewis County	7	1.46%	77440	1.06%
Lincoln County	1	0.21%	10700	0.15%
Mason County	3	0.62%	63190	0.86%
Okanogan County	2	0.42%	42110	0.58%
Pacific County	4	0.83%	21250	0.29%
Pend Oreille County	9	1.87%	13370	0.18%
Pierce County	49	10.19%	859400	11.76%
San Juan County	4	0.83%	16510	0.23%
Skagit County	10	2.08%	124100	1.70%
Skamania County	3	0.62%	11690	0.16%
Snohomish County	43	8.94%	789400	10.80%
Spokane County	6	1.25%	499800	6.84%
Stevens County	3	0.62%	44510	0.61%
Thurston County	47	9.77%	276900	3.79%
Wahkiakum County	0	0.00%	4030	0.06%
Walla Walla County	0	0.00%	61400	0.84%
Whatcom County	24	4.99%	216300	2.96%
Whitman County	1	0.21%	48640	0.67%
Yakima County	3	0.62%	253000	3.46%

Appendix C: Invasive Species Reports per County