

Viewpoint**Invader Detectives: EDRR in Urban Landscapes**Mark Frey^{1,*} and Jamie K. Reaser²¹National Park Service, 100 Alabama St., SW, Atlanta, GA 30303, USA²Giving Voice to Resilience, LLC, Affiliate Faculty at George Mason University, and Adjunct Faculty at the University of Rhode Island, 1207 Bull Yearling Road, Stanardsville, VA 22973, USAAuthor e-mails: Mark_Frey@nps.gov (MF), jamiekreaser@gmail.com (JKR)

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OPEN ACCESS**Abstract**

Stopping invasive species early in the invasion process has the potential to save hundreds of billions of dollars and avert damage to agriculture, natural areas, and human health. While urban areas pose particular challenges to early detection, they also present special opportunities. Urban areas and their ports of entry host higher concentrations of invasive species and, with increasing travel and transport, the number of species introduced to urban areas will increase. Along with many invasive species, urban areas contain many citizens interested in being citizen scientists and the potential for taxonomic experts to be associated with major institutions of learning. Early detection is an effective strategy and citizen scientists are effective data collectors. We present a model called Invader Detectives that harnesses existing data collection by citizen scientists to support early detection of invasive species in urban areas. The data-driven approach is being implemented as a pilot project in the metropolitan Washington DC area but we hope to find partners in urban areas across the country to create a nation-wide network of Invader Detective chapters. The Invader Detectives structure is reviewed and lessons learned are reported.

Key words: early detection, rapid response, citizen science**Introduction***Urban areas and invasive species*

Removing invasive species in cities can protect the important resources outside of urban areas and valuable resources within urban areas. Although urban areas usually support lower species diversity than the natural areas they replace (Chace and Walsh 2006; Marzluff 2001, cited in Shochat et al. 2010), urban areas continue to host important natural resources and industrial infrastructure that are themselves threatened by invasive species (van Ham et al. 2013). There may even be cases where native species find refuge in urban areas as the less urban parts of their population are displaced by invasive species (Plowes et al. 2007).

Urban areas host many pathways for invasive species introductions and pose challenges for detecting and responding to those introductions including: 1) small average parcel sizes that require coordination with

many property owners; 2) biotic resistance that has been reduced by fragmentation, disturbance, and pollution, as well as ecological processes altered by elevated temperatures, artificial lighting, and other features of the urban landscape; and 3) the presence of a wide variety of ruderal landscapes that are suitable for a range of non-native species (Gaertner et al. 2016). In addition to these particular challenges, urban areas present special opportunities. Urban areas are home to many people who can and do look for and report species of interest. There are more professional taxonomists and other biological experts associated with major institutions of learning associated with urban areas (e.g., universities, zoos, aquaria, botanic gardens, museums) to play a role in programs designed to find and identify species in the field.

Many high-impact invasive species were first reported in or near urban areas and have since spread. For example, emerald ash borer (*Agrilus planipennis* Fairmaire, 1988) was discovered near Detroit, Michigan in 2002 (Haack et al. 2002) and is now causing impacts across eastern North America (Morin et al. 2016). Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky, 1853) was discovered in New York City, New York in 1996 (Haack et al. 1996) and has led to quarantines in parts of Massachusetts, Ohio, and New York (U.S. Department of Agriculture 2019). Japanese stiltgrass (*Microstegium vimineum* (Trin.) A. Camus, 1921 [1922]) was first recorded in the US near Knoxville, Tennessee in 1919 (Fairbrothers and Gray 1972) and is now present throughout the eastern US (EDDMaps 2019).

Ports of entry

Urban areas host increasing concentrations of people, conveyance infrastructure, and commerce activity; (Anderson et al. 2015; Banks et al. 2014; Bellard et al. 2016; Dalmazzone and Giaccaria 2014; Early et al. 2016; Jenkins 1996). Already at over seven billion people, the world is expected to add a billion people between 2017 and 2030 and another billion by 2050 (United Nations 2017) and higher human population density is correlated with higher invasive species density (Bellard et al. 2016; Besek and McGee 2014). Globalization is leading to further increases in trade and transport via various conveyances and pathways (Tatem 2009). As commerce and travel increase, propagule pressure will increase, leading to increased numbers of introduction events unless effective interdiction measures are put in place (Reaser et al. 2008). The shift to more internet commerce may increase the distance traveled for goods, and therefore increase the likelihood of introducing species to new areas, as well as increasing the direct sale of invasive species themselves (Lenda et al. 2014).

US Customs and Border Protection operates in 328 ports of entry across the country (Department of Homeland Security, Office of the Inspector General 2014). Of the top 25 US ports (measured by tons of goods moved)

only three are not associated with urban centers (Tomer and Kane 2015). Although most urban areas do not host a major airport or seaport, all urban areas feature aggregations of vectors tied to human commerce and translocation. It is the presence of these smaller-scale entry points that warrant urban areas as the focus of this project.

EDRR terminology and practice

The early detection of and rapid response to invasive species (EDRR) is widely and rightly heralded as an essential component of invasive species policy and management (Reaser 2020). Due to historical inconsistency in terminology, herein we conform to the usage established in Reaser et al. (2020a) which defines detection to mean “the process of observing and documenting an invasive species” and response to mean “the process of reacting to the detection once the organism has been authoritatively identified and response options have been assessed.” Our project was developed as a ground-truthing pilot project to complement this conceptual framework. We thus encourage our readers to review the conceptual diagram presented within Reaser et al. (2020a, fig. 1), which places detection and response in a systematic context and includes other key components of the process, such as identification, planning, and assessment.

Citizen science

Although much attention has been paid to the successful contributions of citizens to data collection for research (e.g., Cosentino et al. 2014; Meentemeyer et al. 2015), less attention has been paid to the role of data collection by citizens for building data sets to inform management actions. Because there is currently insufficient information to make some of the most pressing invasive species management decisions, data collection and mobilization are indefinite needs. Trained volunteers can be reliable data collectors and species identifiers (Crall et al. 2012; Delaney et al. 2008; Gallo and Waitt 2011). In particular, citizen scientists have been shown to be effective for early detection of invasive species (e.g., Beale et al. 2008; Froud et al. 2008; Hosking 2003; Jennings 2004; Thomas et al. 2017). In addition to augmenting data collection, project participation can encourage citizen scientists to expand and intensify engagement with their environment (e.g., learning to identify native species) and may even encourage community-based conservation (Lawrence 2006; e.g., volunteering to remove invasive species on public lands). Skilled volunteers can enhance the capacity to respond to invasive species infestations (e.g., Stien and Hausner 2017).

The Invader Detectives project we describe was developed, in part, to increase awareness of the potential for citizen scientists to engage in EDRR, as well as the collection of non-native species occurrence data in and around those areas most likely to be initial introduction points for non-native species

Table 1. A summary of the three components of Invader Detectives.

	What to do	How often	Where
Alerts	Report anything of interest	Always	Anywhere
Watch Lists	Look for a small group of species on the list	Always	Anywhere
Target Areas	Report new species	Monthly	Designated spot

in the US. The project described here is the first to test and showcase the Invader Detectives conceptual model.

Program Design

Overview

Our primary objective for Invader Detectives (ID) was to create a program that would help citizen scientists quickly find new invasive species in urban areas across the US. We determined that leveraging citizen scientists would enhance the potential for detection and focusing on urban areas would allow us to focus on species introduction hot spots.

Once the ID concept was identified, we chose the Washington DC metropolitan area as the urban area for the pilot project and established a Planning Team with representation from a geographically diverse range of professionals with a wide range of expertise. Hui et al. (2017) identify Washington DC as second only to Atlanta, Georgia in its list of invasive species spread potential in global cities. The Planning Team contained representatives from a large public landholder, county governments, local non-profits, and the local port. Expertise included citizen science, urban forestry, entomology, nurseries, landscaping, urban wildlife, data management, and taxonomy. The Planning Team also set the taxonomic scope to include all non-microbial taxa and the environmental scope to include both terrestrial and aquatic areas. The Planning Team developed a three-pronged strategy involving Target Areas, Alerts, and Watch Lists (Table 1). To support each of these efforts we first had to establish a data aggregation process.

To ensure we were not duplicating efforts, we reviewed the objectives of existing organizations and projects and found many valuable efforts focused on plants (e.g., Mid-Atlantic Invasive Plant Council: <https://www.maipc.org/>, the DC-Cooperative Weed Management Area: no longer active, Maryland's Statewide Eyes program: https://dnr.maryland.gov/wildlife/Pages/statewide_eyes.aspx), on portions of the DC metro area (e.g., the Northern Virginia PRISM: no website, Maryland Invasive Species Council: <http://mdinvasives.org/>), or on much larger areas (EDDMaps: <https://www.eddmaps.org/>, iNaturalist: <https://www.inaturalist.org/>, Mid Atlantic Early Detection Network: <https://www.eddmaps.org/midatlantic/>, Mid-Atlantic Panel on Aquatic Invasive Species: <https://www.midatlanticpanel.org/>), but none dealing with all taxa and a metropolitan area focus. The existing projects were regarded as potentially complementary building blocks for our approach.

To guide the project, we created an Operations Manual, a guidance document specific to the DC chapter, and a How To guide to introduce volunteers to the basics of how to participate in Invader Detectives. For a thorough overview, see Frey (2018, <https://www.doi.gov/invasivespecies/early-detection-and-rapid-response>). The Operations Manual serves as an authoritative repository of methods and guidance for project organizers and carries forward the intent of the organization as personnel change at member organizations. The How To guide provides clear guidance to volunteers with overview information such as who the organization includes, what is the purpose of the program, why they should participate, and specific instructions about how they can participate. The chapter guidance document provides information for other geographic areas on how to set up their own ID chapter.

Early detection strategies

Targeted area search, watch lists, and alerts are three early detection tools. Targeted searching is needed because finite searching time must be spent strategically (Hauser and McCarthy 2009). Watch lists are often defined as a list of species that are absent or uncommon but are deemed likely to occur in the area of interest and have a high potential to cause harm. Watch lists may serve one or more goals including to 1) provide location information for a species that may or may not be common but is likely under-reported, 2) increase the chance of finding the first record of a species of great concern that is not yet known from the area, 3) encourage reporting by making participants feel valued, 4) provide information to support a species-specific control effort, and 5) provide location or other information for a local study on some species or group of species. Watch lists are often produced using expert opinion but should rely upon the best available science (Reaser et al. 2020b). There are only a small number of systematic processes that have been published. Faulkner et al. (2014) built a watch list for South Africa that included species that were: non-native, reported as invasive elsewhere, absent from South Africa, had occurrence data, were found in similar climates as the target area, and had the potential to be introduced. Frey (2017) used a system specifically for plants and for national parks in the region in and around Washington DC; species had to be not reported in the area of interest, reported nearby, and ranked high using the Invasive Species Assessment Protocol (Randall et al. 2008). An alert is a timely notification of a species that has recently been found in the area of concern or has recently been observed to be invasive. Like watch lists, alerts are often produced using expert opinion such as the Maryland Invasive Species Invader of the Month (Maryland Invasive Species Council 2019) and the US Forest Service Weed of the Week (U.S. Forest Service 2017).

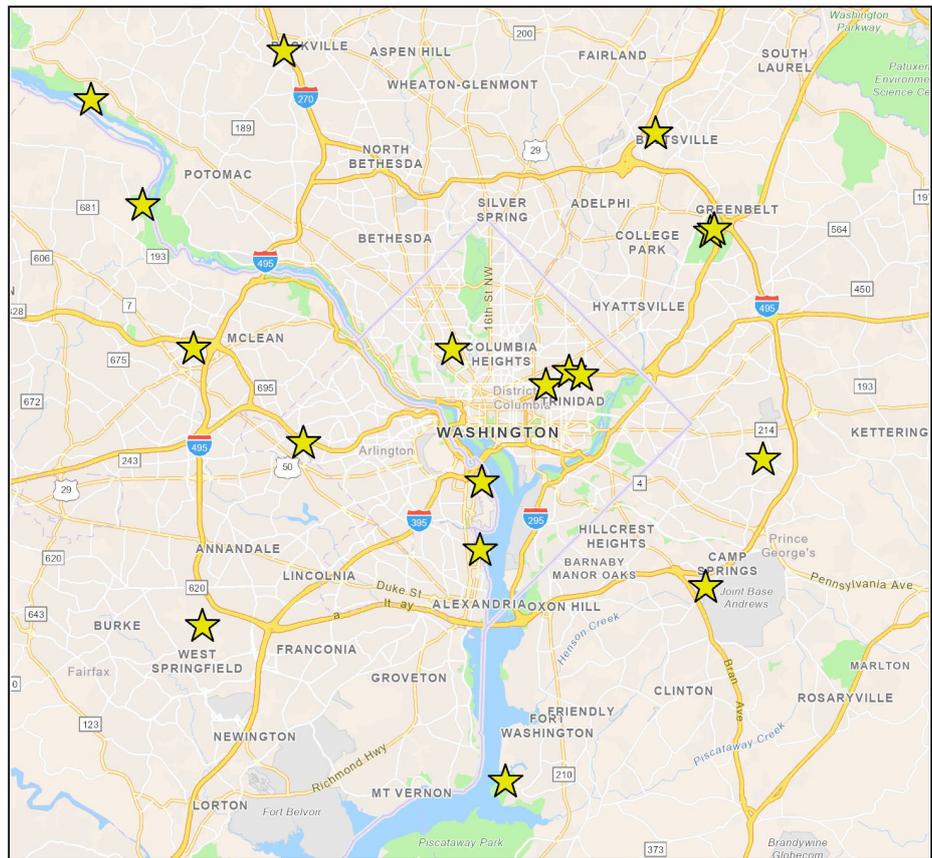


Figure 2. Preliminary locations of the top 20 areas to search.

Although there is not yet a US-wide organization for early detection (Reaser 2020), the National Plant Diagnostic Network (NPDN) created a state-based program for finding “plant pathogens, arthropods, nematodes, and weeds” called First Detector.

Target Areas process

The Target Areas strategy of ID required us to first identify the types of pathways of particular concern in the Washington DC metro area; we identified railways, highways, and rivers. Second, we searched on a map for areas where those pathways were most concentrated and where it was possible for a member of the public to survey without seeking permission. These were either public areas (e.g., parks), or areas that could be viewed from public areas. Once this initial set of locations was identified we looked for areas that were under-represented in search locations and filled in the gaps until we reached 20 locations (Figure 2). Twenty was chosen because that was our estimate of the number of volunteers we could recruit for this part of the project. We left open an unlimited number of slots for backyard surveys. The team or individual managing the local ID project will assign volunteers to locations.

In addition to identifying areas to search we will ask searchers to focus on general priority locations within the landscape including human corridors,

natural corridors, utility lines, industrial sites, and other high disturbance areas. We initially identified specific landscape locations that we thought would be areas likely to result in species discoveries including utility boxes, below plate glass windows, around streetlights, and at trail heads. However, we did not specify these locations because:

- Utility boxes can be hard to find, and volunteers might be put at risk of injury or suspicion if they were looking in utility boxes.
- Plate glass windows may kill or stun birds at night but there are so many birders that this strategy seemed unlikely to identify new bird species not otherwise reported.
- Although flying insects and bats will congregate under and around streetlights, we were advised by experts that the lights are only valuable if the light is remote from other lights.
- Trail heads often host a high density of invasive species, but these locations are most valuable at the park level rather than at the landscape level.

Volunteers will use the iNaturalist tools (smart phone app or web-based tools) to record what they find. It was important to the Planning Team that no special app was required so that the project could maximize the amount of data collected. Data used in our effort includes geographic information and a photograph.

Alerts process

The Alerts process is the most data-intensive of the three strategies. Our goal was to have a customized query provide us with a short list of records within our area of interest. To make the list short and valuable it would need to exclude both native species and those non-native species that were too common to be early detection targets. We developed an alert system using existing iNaturalist tools that uses a geographic filter to only view records in Washington DC and adjacent counties and a taxonomic filter to exclude species that are not of interest. Excluded species include those that are native, those that are non-native and not currently invasive, and those that are non-native and common. See Supplementary material Appendix 1 for information on building the taxonomic filter and Figure 3 for a summary.

Watch list process

Once the Alerts process was established, the species that made it through the filter on 7/1/2017 were separated into enviro-taxonomic groups (Aquatic vertebrates, Aquatic invertebrates, Terrestrial vertebrates, Terrestrial invertebrates, Terrestrial plants, Aquatic plants, Plant diseases and pests). Only Research Grade records were used. Research Grade records have geographic information, a photograph or sound file, and at least two thirds of identifications agree. Each species on each list was further evaluated to

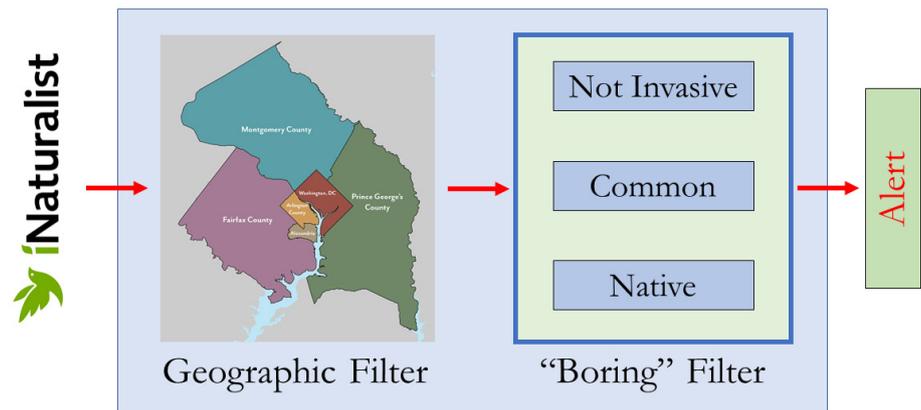


Figure 3. A model of the data filtering process.

ensure the species was uncommon, non-native, and invasive. For those groups with fewer than twenty candidates we sought suggestions of species to add from reputable lists for our area or adjacent areas (e.g., Aquatic Nuisance Species Taskforce, AmericanHort, Pennsylvania invasive species list). If the list was longer than 60 species, we sought additional expert opinion and did additional research on each species. Each list of twenty species was further refined to ten species so that the list was manageable for non-experts.

Once each list was narrowed down to ten species we created electronic files for the watch lists that included basic information about the native range, the introduced range, estimated prevalence in the introduced range, key identifying characteristics, a photograph, and a QR code link to additional online information. In addition to paper Watch Lists we used the Encyclopedia of Life Collections to create each list electronically. The Collections were then used as the basis for Guides in iNaturalist. The Guides allow users to have easy access to information for all species on a given watch list on their smart phones. When users click on each photo they see a map of records nearby and basic information about how to identify the species, taxonomic information, and distribution information.

Lessons Learned

Ensure Invader Detectives has a home

Invader Detectives (ID) is a new model available to support effective early detection programs but, to be successful, that model requires a dedicated team with the tools and funding needed to collect and act on current data. The pilot chapter of ID in Washington DC is now a project of the National Capital Region Partnership for Invasive Species Management (NCR-PRISM; see Box 1) with a coordinator funded to begin in 2020. Because of the impacts of COVID-19 and other administrative hurdles, the NCR-PRISM has been delayed by almost a year in the implementation of the funded project to implement ID-DC. Lessons learned presented below are based

BOX 1: NCR PRISM

The National Capital Region Partnership for Invasive Species Management (NCR-PRISM) grew out of the DC Cooperative Weed Management Area (DC-CWMA) and was officially launched in 2018. The DC-CWMA only dealt with invasive plants and only dealt with the District of Columbia. The NCR-PRISM deals with all taxa and includes every county adjacent to DC (covering approximately 1,500 mi²). The PRISM includes local and federal government agencies, conservation organizations, and academic institutions in the Washington, DC region. The mission of the PRISM is to minimize the impacts of invasive species on ecosystems throughout the DC area.

In 2019 the NCR PRISM worked with the National Environmental Education Foundation (NEEF) to identify a project to implement Invader Detectives in the Washington DC metropolitan area beginning in 2020. Approximately \$200,000 is going towards a full-time coordinator and to conduct invasive species management on high priority species in each of the component jurisdictions. The coordinator will promote regional invasive species management through outreach and events, implement Invader Detectives, facilitate a multi-jurisdiction effort to eradicate a new aquatic invasive water chestnut species in the Potomac River watershed, and assist members with restoration and biodiversity projects. Several members of the PRISM will implement supplemental projects, proposed in separate applications under this same grant umbrella. Those will be discrete projects that will focus on invasive plant management and habitat restoration in specific areas, to improve biodiversity and restore wildlife habitat. The projects will include education, invasive species management and restoration in riparian forests in Montgomery County in Maryland, forest and meadow restoration in Fairfax County, Virginia, and forest restoration in Rock Creek Park in the District of Columbia.

upon the Planning Team process, as well as discussions with the Steering Committee for the NCR-PRISM.

Create a Planning Team

In line with recommendations from reviews of citizen science projects by Bonney et al. (2009), we recommend the coordinators of any ID chapter identify a Planning Team to provide guidance and expertise. Explicitly defining the geographic extent of the effort and using political boundaries help reduce confusion about which municipalities should participate in ID. In addition, the Planning Team must determine if there are reasons to exclude any taxonomic groups or aquatic ecosystems. Securing commitments from member organizations to allow Planning Team members to spend time participating in the program will improve the Planning Team's efficacy. Funding to support a dedicated coordinator would reduce the burden on Planning Team members.

Diversity leads to resilience

A Planning Team bias for one jurisdiction, one taxonomic group, or one kind of impact may lead to choosing an occurrence to respond to that is not the highest priority occurrence. Similarly, including staff and volunteers with diverse expertise and from across the geographic area will increase the likelihood of success.

Build tools for participants

Invader Detectives is made up of staff, volunteers, and data providers. Providing each group with enough information so that they want to participate and do a thorough job but not so much information that they become overwhelmed requires careful planning. Organizers need an Operations Manual to serve as the official repository of methods and the document that details how to make the program work. Those collecting information need a How To guide that provides enough information so that they can decide whether to participate and, if interested, how to participate.

If watch lists are broken into enviro-taxonomic groups, participants can focus on the types of species for which they have the most expertise. In addition, watch lists should be made available on smart phones so they can be readily updated and accessed.

The Planning Team should develop a library of response plans that can be adapted for future use. These drafts can save time when an actual response is needed.

Leave enough time to do a good job

Setting up a robust ID program requires many hours to plan and organize and hundreds of hours to assess species. Because some taxonomic groups are particularly under-studied (Simonetti 1997) and the number of taxonomists is declining (Hopkins and Freckleton 2002; Kim and Byrne 2006), it will likely continue to be a challenge to dedicate the hours required. We recommend spreading the work over at least a few months and at least a few people. A longer time frame leaves time for identifying and then incorporating additional data sets, data sorting, data gathering information for thousands of species, creating tools for volunteers, and careful planning. The coordinators can also use the expertise of the Planning Team to make smart decisions and to establish sub-committees to target specific needs (e.g., outreach).

Don't re-invent the wheel

Technology has transformed what citizen scientists can contribute (Bonney et al. 2014). Take advantage of existing platforms for data collection, tools for species identification, organizations for program management, and existing training for Detectors. Although a new chapter may have the time and energy to put on separate events in the first year, it is unlikely that the chapter can sustain the staffing and time needed to continue those efforts. Time spent planning and implementing events and training reduces the time available for detecting and controlling species. Coordinators should share data, species assessments, and lessons learned from response actions.

Volunteers are valuable

Volunteer Detectors are essential to success. Coordinators should encourage participation and plan on strategies to recruit and retain citizen scientists. For Invader Detectors, professionals are also volunteering to report and collaborate – staff recognition should be part of the plans to recruit, train, and retain. Once the NCR-PRISM project is fully implemented, a full-time coordinator will be available to recruit and coordinate volunteers.

Put agreements in place

Shorter agreements are easier to review and harder to find fault with. Coordinators should make sure the agreement establishing the ID chapter is structured so that each organization signs independently of other organizations rather than listing all expected signers within the agreement itself. Not explicitly listing organizations allows the organization to proceed even if one-member organization takes years to sign or changes its name and it also allows other organizations to sign on without having to have all organization sign a new document. Because of issues including liability, control actions will likely require separate agreements with only one or two organizations (the land owner and the responders) included.

Identify target areas to survey monthly

When selecting areas to search regularly, coordinators should choose sites that include many potential invasion pathways, are geographically distributed across the area of interest, and don't require Detectors to seek permission to enter.

Spread the word

When a new ID chapter is launched, a kick-off event should be held so that staff and volunteers can learn more about the project, get energized, and commit to taking specific actions. Once the ID effort is underway, information should be shared with stakeholders of all kinds. In particular, when a species is found, the relevant government agencies (in particular landowners, state extension, state natural resources) must be notified immediately.

Plan ahead

Before any response action is needed, coordinators can perform many tasks so that response time is faster and success more likely. Consulting local compliance specialists in each of the local jurisdictions well ahead of any potential response will speed up the process of responding. A list should be created of all agencies with jurisdiction that might need to be involved in a response. Agencies may have jurisdiction based on taxonomic groups, geographic area, affected human population, or affected resources.

A successful chapter maintains capacity in staff, equipment, and supplies. Capacity building includes ensuring cooperating organization staff are trained in the Incident Command System and in a range of control methods.

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Supplementary material

The following supplementary material is available for this article:

Appendix 1. Refining the Taxonomic Filter.

This material is available as part of online article from:

http://www.reabic.net/journals/mbi/2021/Supplements/MBI_2021_Frey_Reaser_SupplementaryMaterial.pdf