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Research Note

Using Citizen Science Observations to Develop Managed Area Watch Lists

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ABSTRACT

Invasive species are a major threat to natural ecosystems. To combat the destructive potential of arriving invasive species, many natural resource managers have adopted an "early detection and rapid response" (EDRR) strategy. A key component of EDRR is a "watch list" of invasive species that have yet to be detected in a managed area and are prioritized for surveillance, reporting, and other responses. However, managed areas with limited resources may not have the capacity to develop useful watch lists. To address this need, we developed an automated process to use data from iNaturalist, a popular citizen science platform, and a United States national list of nonnative plant species to compile a provisional watch list of the 100 most frequently reported nonnative species within a 160 km buffer around a managed area. We demonstrated the application of the process using 36 US National Park Service units with relatively small operating budgets. Using Fort Vancouver National Historic Site, Washington, as an example, we show how provisional watch lists can be refined by removing species that are unlikely to occur in the unit due to the absence of suitable habitat and prioritizing species from the state priority invasive plant list. The automated process has the advantage of being easily repeatable at regular intervals to alert managers of newly arrived species. Managers can readily modify this method for use anywhere if they have access to observation data from a citizen science platform and a list of nonnative species in the area of interest.

Index terms: citizen science; early detection rapid response; invasive species; managed areas; watch list

INTRODUCTION

Invasive species are well known to wreak substantial ecological harm to biological communities (e.g., Pyšek et al. 2012; Gallardo et al. 2015). Attempts to lessen the impact of invasive species by eradicating or controlling them can be a major cost for protected areas managers (Pimentel et al. 2005). Numerous strategies are available to combat nonnative species (Ruiz and Carleton 2003; Hulme 2009). Because of the great cost and often futility of eradicating nonnative species once they become established, managers have increasingly attempted to follow an "early detection and rapid response" (EDRR) strategy to prevent wide and extensive outbreaks (Reaser et al. 2020a). EDRR comprises several components, including target analysis (determining the effort needed to detect an invasion), detection, identification, reporting, risk screening, feasibility screening, and response (Reaser et al. 2020a).

Watch lists, defined as lists of invasive species to be prioritized for surveillance, reporting, and other responses that may reduce the risk of impact to valued resources, can serve as an important tool for the target analysis component of EDRR (Frey 2017; Reaser et al. 2020b). For this project, we consider watch lists as lists of species that have not been recorded in the area under management but may arrive and present management challenges in the future. Watch lists can help managers prioritize the types of habitats where ongoing surveillance for nonnative species takes place and to guide the selection of survey techniques employed to search for newly arrived nonnative species. Watch lists can also help managers determine the equipment, training, and other needs to facilitate rapid control responses in the event of an arrival of a new nonnative species. For example, the equipment needed to deter an invasive aquatic plant is distinct from that used to control an invading insect herbivore.

By their nature, watch lists cannot usually be developed empirically from survey data. In most cases, they require expert knowledge of the nonnative species occurring in the region surrounding a managed area. However, many managers lack sufficient resources and staff capacity to develop watch lists. State floras can help to identify nonnative plant species, but they are typically updated too infrequently (compared to the rate of arrival of nonnative species) to serve as the sole source of input into a watch list. For example, the flora for New York was last published in 2017 (Werier 2017), updating the previous 2003 list (Mitchell and Tucker 2003). During that 14 y period, 263 nonnative species were added (Werier 2017). Also, for large and/or ecologically heterogenous states, state-level records of nonnative species are less useful because of the uncertainty of the proximity of records to a particular managed area (and therefore the likelihood of invasion into the managed area).

Citizen science (also known as "community science") schemes and the access they provide to broadscale observations across species' ranges present an opportunity to create provisional watch lists in the absence of expert knowledge about

regional biota. With a list of nonnative species occurring in a country or region, it should be possible to mine databases of georeferenced citizen science observations to develop watch lists for managed areas. To be successful, such an exercise should take place in an area where the citizen science scheme is in broad use (i.e., at least hundreds of observations of nonnative species each year), the species of interest are reliably identifiable by citizen scientists, and the data are made available soon after observations take place. Although citizen science observations are inherently incomplete and the level of incompleteness is unknown, they nonetheless have the potential to provide useful information in the absence of more rigorous survey data.

Here we demonstrate a novel use of observation data made available through iNaturalist (iNaturalist 2020) to develop provisional watch lists of nonnative plants for US national park units with limited budgets. iNaturalist enables users to share georeferenced images and other media of plants and animals on a mobile-friendly platform. We describe and make available a series of scripts that draw from a master list of nonnative species to extract records of these species occurring within a defined buffer of a national park unit, but that are not yet recorded in the park. We summarize the results of this exercise, describe the experience of an independent team implementing the process, suggest ways to refine the output to make it more useful for managers, and discuss taxonomic considerations, sourcing of lists of nonnative species, and challenges that arose. Our method can be adopted to develop provisional watch lists for both plants and animals in managed areas worldwide.

METHODS

Park Unit Selection

On the assumption that well-funded parks have the resources to develop their own watch lists, we focused this study on the smaller units of the National Park Service (NPS) in the United States. To increase the chances that the units had been adequately visited and surveyed by citizen scientists, we limited the sample to the 129 units that participated in the 2016 NPS centennial bioblitz (da Silva 2018), which used iNaturalist as the data entry platform. Bioblitzes in units do not guarantee that surrounding areas have been well surveyed but do decrease the likelihood of falsely identifying a watch list species that already occurs in the unit. To ensure a geographically representative sample and focus on units with less funding and therefore a presumed lack of capacity to develop watch lists, we selected the units that fell in the lowest third for budget appropriation in 2019 within each NPS administrative region. We obtained the budget figures from the scorecard database maintained by the National Park Service Business Management Group. Focusing on the units with less funding increased the chances that the unit did not already have a watch list. We removed from consideration units that do not have any natural areas to manage. We also did not include units from Hawaii where much of the buffer area is ocean and therefore not suitable habitat for invasive plants. In addition, Hawaiian parks already invest heavily in the eradication of invasive plants, which are a major threat to native species (Pimentel et al. 2005). From 120 units with budget information, these criteria yielded a focal list of 36 units (Figure 1). The average annual appropriation for the focal units was US $1,442,361 (range $350,000–$3,537,000), compared with an average annual appropriation of US $8,614,466 (range $1,805,000–$35,687,000) for the units not included in the study.

List of Nonnative Species

We used the USDA PLANTS list of introduced plants to the United States (USDA and NRCS 2020) as our reference list of nonnative species. We focused on full species and varieties, ignoring hybrids (which add taxonomic complexity and redundancy) and taxa listed only at the genus level (typically not useful for making management decisions).

iNaturalist

iNaturalist has grown since its inception in 2008 to be an important web and smartphone-based platform for sharing georeferenced natural history observations as images and other media formats (Nugent 2018). iNaturalist records have led to new species descriptions (Winterton 2020) and range extensions (Jones et al. 2019), supported vegetation mapping (Uyeda et al. 2020), and provided input to regulatory decisions in the United States and Canada (Young et al. 2019). Studies show that identification accuracy is usually adequate for many research purposes, although this may vary across taxonomic groups (Hochmair et al. 2020). As of the time of our research in June 2020, iNaturalist housed approximately 11,000,000 observations of 24,000 US plant species recorded by 490,000 observers and verified by 58,000 identifiers. Of the 11,000,000 iNaturalist plant observations in the United States, over 700,000 observations occurred within units of the National Park Service, accounting for roughly 6.5% of all plant observations in the country. The records are accessible via an application programming interface (API) that facilitates their use in research. Records of some sensitive species are hidden from public access, but records of nonnative species, the subject of this study, are typically open access.

Occurrence of Nonnative Plants

Using the R programming language, we developed a series of scripts derived from the *iNatTools* package (Hanly 2020) to extract records of the species on the USDA nonnatives list that were recorded by iNaturalist contributors within 160 km of each of the focal parks. We selected 160 km to include most day trips to the park, assuming that park visitors are the primary means of spreading nonnative plants. We used only "research grade" observations, meaning they had a photo, date, geographic coordinates, and an identification agreed upon by at least two-thirds of identifiers (the minimum is two observers who agree on the identification). Observations made on any date were considered. The scripts and instructions on how to use them are posted online (https://github.com/NatureServe/inat-nps-download).

Derivation of Watch Lists

To derive provisional watch lists for each unit, we identified all species with records inside the 160 km zone but not inside the unit's boundaries. Because exceedingly long watch lists can be

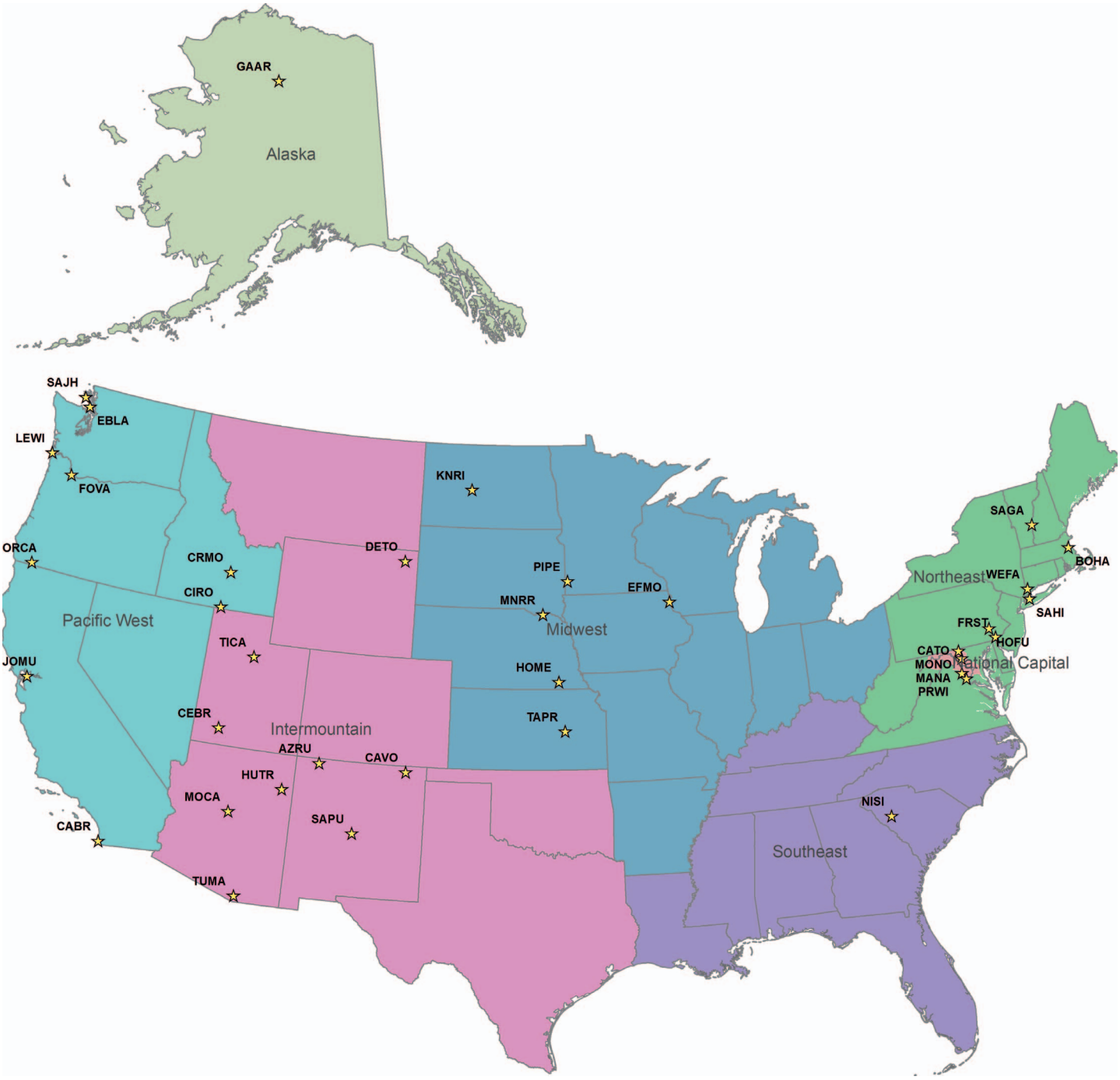

Figure 1.—Locations of US National Park Service (NPS) units included in the study. Unit codes as in Table 1. Colors separate NPS administrative units used to stratify the units addressed in the study.

unwieldy and perhaps less helpful to resource-limited land managers, we arbitrarily truncated each list at 100 species, prioritizing the species with the greatest number of records in the buffer. In the case of a tie between the 100th most recorded species and other species with the same number of records, we included the additional species, yielding lists slightly longer than 100 species in some cases. The final watch lists include both the list of species and the corresponding number of records within 160 km of the unit.

Species Occurrence Maps

One of the R scripts created maps showing the occurrences of each species on the resulting watch list. Two maps are generated: one of the entire 160 km zone around the park and one closeup of the park that shows the locations of the closest observations to the park, if there are any. We used the "nps_boundary" file from NPS's Integrated Resource Management Applications system (https://irma.nps.gov/DataStore/Reference/Profile/2225713) for park boundaries. To demonstrate how the spatial orientation of

a species' records could influence interpretation of its presence on a watch list, we mapped records for two illustrative nonnative species occurring in the buffer around Fort Vancouver National Historic Site.

Practical Application

To provide a real-world test, NPS staff implemented the protocol for the parks served by the Gulf Coast Invasive Plant Management Team. They ran the R scripts for all NPS units in Louisiana and Mississippi and four units in eastern Texas. We report on their experience, emphasizing their experience at Jean Lafitte National Historical Park.

RESULTS

Among the 36 park units, there were 0–119 (mean 27.4, SD 27.1) nonnative species recorded within their boundaries and 0–875 (mean 417.3, SD 279.1) nonnative species outside their boundaries but within the 160 km buffer (Table 1). The number of iNaturalist records for nonnative species recorded both within park units and in the buffers varied across several orders of magnitude (Table 1). The full watch lists generated for each unit are presented in Table S1, with species listed in decreasing order by the number of records. Sample output maps are shown in Figures S1 and S2.

Figure 2 shows the locations of iNaturalist records for 2 nonnative species occurring in the buffer area around Fort Vancouver National Historic Site located in southern Washington. In this example, *Cakile maritima* Scop. has numerous records within the buffer but is restricted to the coast and therefore likely does not pose a threat to Fort Vancouver. *Sorbus aucuparia* L., on the other hand, has been recorded throughout the terrestrial area surrounding Fort Vancouver and therefore may pose a true threat.

NPS personnel were able to implement the process successfully for all established units with natural areas. They identified small changes needed in the script to improve the workflow and results, such as adding the analysis date to the output maps. We subsequently revised the script accordingly. For Jean Lafitte National Historical Park, the team supplemented the USDA nonnative species list with local lists of nonnative species for a more complete search for nonnative species. Care must be taken when doing this as duplicate species can appear on the draft watch list when taxonomic synonyms occur on the different nonnative species input lists. A botanist reviewed the list for Jean Lafitte, (1) identifying several species on the draft watch list that had been recorded in the park but not in iNaturalist and (2) noting some important invasive species in the region of the park that were detected by iNaturalist participants but not frequently enough to appear in the top 100 species in the draft watch list.

Table 1.—Species counts and numbers of records of nonnative plants found within US National Park Service units or in a 160 km buffer surrounding the unit (and not in the unit itself). Abbreviations: NHP, National Historical Park; NHR, National Historical Reserve; NHS, National Historic Site; NM, National Monument; NP, National Park; NRA, National Recreation Area.

		In NPS unit		In buffer	
National Park unit	Code	Species	Records	Species	Records
Aztec Ruins NM	AZRU	3	4	98	728
Boston Harbor Islands NRA	BOHA	119	1106	617	53,239
Cabrillo NM	CABR	67	352	712	65,498
Catoctin Mountain Park	CATO	31	121	703	71,807
Capulin Volcano NM	CAVO	6	19	81	404
Cedar Breaks NM	CEBR	2	4	107	632
City of Rocks National Reserve	CIRO	6	10	169	3036
Craters of the Moon NM and Preserve	CRMO	5	15	151	3024
Devils Tower NM	DETO	7	30	89	767
Ebey's Landing NHR	EBLA	50	113	652	48,731
Effigy Mounds NM	EFMO	0	0	327	10,142
Fort Vancouver NHS	FOVA	39	62	629	27,379
First State NHP	FRST	35	64	797	124,508
Gates of the Arctic NP & Preserve	GAAR	0	0	0	0
Hopewell Furnace NHS	HOFU	18	24	748	94,501
Homestead NM of America	HOME	13	26	260	2603
Hubbell Trading Post NHS	HUTR	0	0	48	213
John Muir NHS	JOMU	63	144	875	124,716
Knife River Indian Villages NHS	KNRI	21	45	79	452
Lewis & Clark National Historic Trail	LEWI	76	198	580	20,810
Manassas National Battlefield Park	MANA	71	476	713	70,881
Missouri National Recreational River	MNRR	14	25	200	1594
Montezuma Castle NM	MOCA	17	28	248	5885
Monocacy National Battlefield	MONO	38	64	701	70,637
Ninety Six NHS	NISI	30	43	434	6550
Oregon Caves NM and Preserve	ORCA	9	11	381	7078
Pipestone NM	PIPE	35	90	136	1053
Prince William Forest Park	PRWI	29	44	707	69,657
Saint-Gaudens NHP	SAGA	41	108	555	57,744
Sagamore Hill NHS	SAHI	9	9	805	133,824
San Juan Island NHP	SAJH	55	141	651	48,463
Salinas Pueblo Missions NM	SAPU	2	2	233	3008
Tallgrass Prairie National Preserve	TAPR	15	29	223	2795
Timpanogos Cave NM	TICA	6	7	331	6864
Tumacacori NHP	TUMA	11	21	178	2225
Weir Farm NHS	WEFA	44	72	805	134,352
Mean		27	97	417	35,439

DISCUSSION

This study demonstrates the potential utility of citizen science data for automating the development of provisional watch lists to contribute to EDRR programs at areas managed for biodiversity protection. These lists can serve as draft versions of watch lists that could be refined using a variety of other tools as discussed below. These initial lists can be quickly generated and do not require any botanical expertise.

The provisional watch lists created with citizen science data can be improved in several ways, all of which refine the list to species posing the greatest risk. First, as demonstrated in Figure 2, the distribution of species on the list can provide clues about the degree to which they threaten to disperse and establish in the managed area. In this example, a coastal species was highlighted as likely to be unthreatening. In other contexts, species restricted to elevations that do not exist in the managed area or those in landforms such as riparian areas that are not found in the protected area can be eliminated from the watch list.

Incorporating botanical knowledge can also aid in interpretation of species on provisional watch lists. Species that grow in

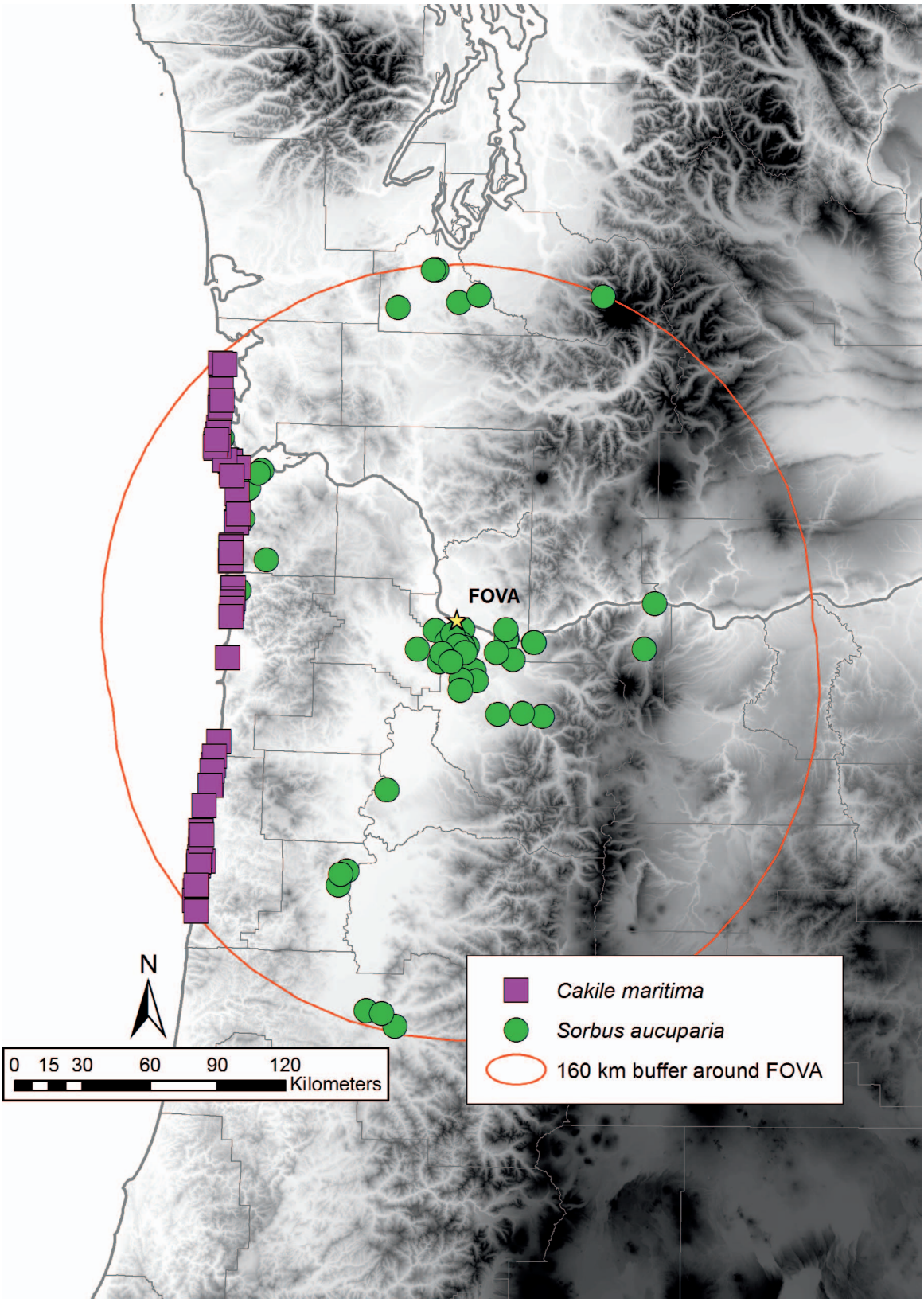

Figure 2.—Map showing the locations of iNaturalist records of two nonnative plants occurring within a 160 km buffer around Fort Vancouver National Historic Site (FOVA) in southern Washington. Shading depicts topography.

microhabitats that do not occur in the managed area could be eliminated. A botanist should also be able to eliminate ornamental or crop species that cannot become established on their own. For example, the nonnative plant recorded most abundantly in the buffer around Fort Vancouver was *Digitalis purpurea* L. The images accompanying some of these records suggest that, although many are likely growing as weeds, others were likely planted as ornamentals (e.g., iNaturalist observation 25874403). Also, as the Jean Lafitte experience demonstrated, a botanist familiar with a park can identify species on a draft watch list that are already known from the park but not detected by citizen scientists.

Additionally, adding information about the invasive potential of species in the region where the managed area is located could help prioritize species on the list (Frey 2017). Several methods are available to assess the potential invasiveness of nonnative species (Morse et al. 2004; Colautti et al. 2014), and databases with the results of these assessments could be compared with the provisional watch list to prioritize known invasive species. Similarly, watch list species that appear on lists published by state invasive plant/species councils or exotic pest plant councils could also be prioritized. For example, the Washington Invasive Species Council lists 25 priority invasive plants and plant groups (https://invasivespecies.wa.gov, accessed 29 Oct 2020). Four of these species (*Alliaria petiolata* (M. Bieb.) Cavara & Grandee, *Buddleja davidii* Franch., *Lythrum salicaria* L., *Polygonum cuspidatum* Siebold & Zucc.) appear on our provisional watch list for Fort Vancouver and should be prioritized for surveys within the site. Four additional species, *Myriophyllum spicatum* L., *Centaurea nigra* L., *Centaurea diffusa* Lam., *Centaurea stoebe* L., were also reported in the buffer, but were not among the 100 most common species and therefore did not enter the default watch list. Given the documented threats they pose to natural ecological communities, these four species should be elevated to appear in the watch list. Similarly, the Jean Lafitte exercise showed that important invasive species that deserve watch list status may not be among the 100 most commonly reported species for the buffer area. This process of risk evaluation is fundamental in developing watch lists for natural areas with high public scrutiny (Reaser et al. 2020b).

Although a watch list drawn up by a local expert is often desirable, there are benefits of following the more automated method we present here. Most importantly, the automated method can be repeated regularly to keep abreast of recently documented nonnative species. A newly compiled list can be compared with one compiled a year previously to identify newly detected and possibly newly arrived nonnative species. For example, the nonnative *Cichorium intybus* L. was not documented by iNaturalist observers in the buffer of Fort Vancouver until 2020 and therefore would not have appeared on an automated watch list generated in 2019.

Except in the case of taxonomic mismatches, the automated method will comprehensively list all species recorded in the observational database used that fulfill the criteria for inclusion on a provisional watch list. On the other hand, experts may be aware of arrivals of nonnative species that have been reported elsewhere. Experts can also filter noninvasive species or those without available habitat on the target managed area more efficiently than can an algorithm. For Fort Vancouver, prioritizing the default watch list by number of records in the buffer missed four important species.

Like many research applications, using citizen science observations for compiling a watch list has advantages and disadvantages. The benefit, of course, is free access to ongoing, often large numbers and geographically distributed observations of nonnative species. Biases in what and where citizen scientists report are well known (Kosmala et al. 2016). Biases that could affect the development of watch lists include avoidance of sites that are inaccessible, far from home, or in areas with low species richness (Mair and Ruete 2016; Tiago et al. 2017). However, many invasive nonnative plants are weedy species that occur along roads or trails, areas that citizen scientists are documented to favor (Mair and Ruete 2016).

Good coverage by citizen science observers of the buffer around managed areas is a prerequisite to using their data to develop watch lists. We found abundant iNaturalist records of nonnative plants in the buffers around most parks, with over 1000 records of nonnative plants at 29 (81%) of the 36 units examined. Fort Vancouver, located near the Vancouver, Washington-Portland, Oregon, metropolitan area with a sizeable pool of potential citizen scientists, had 27,379 records of nonnative plants in the buffer area. This large number of observations confers confidence that the provisional watch list likely contains many important invasive species threatening the site. Even in poorly surveyed areas, the available citizen science data can provide an initial, albeit incomplete, list of nonnative species that potentially could invade a managed area. Note though, that in remote areas such as Gates of the Arctic National Park and Preserve, the lack of invasive species records is most likely due to the lack of observations; citizen science cannot aid in watch list development in these regions. Managers can encourage additional reporting of nonnative species through a targeted project in iNaturalist (which notifies observers to specific needs for observations) and by adjusting their iNaturalist subscriptions to be alerted via email whenever a watch list species is observed within the park boundaries. Additional options include use of an alternative platform such as iMapInvasives (Hinchey et al. 2013) in the United States or by organizing a bioblitz (Baker et al. 2014).

We used a national, digital list of nonnative species to identify recorded species for inclusion in watch lists. This approach facilitated the development of watch lists for NPS units across the United States. In some areas, a state/provincial (e.g., Keener et al. 2020) or regional (e.g., Weakley 2010) flora that distinguishes between locally native and nonnative species may be preferable to the national list, for example by including species that may be native to the country but nonnative to the region of interest.

Regardless of which reference list of nonnative species is used, there will be nomenclatural mismatches with the iNaturalist taxonomic backbone. Plants, with no widely accepted national list in the United States, are particularly prone to this problem. Use of synonyms when matching names can help lower the rate of missing nonnatives that have been recorded in a buffer but are not detected because the name used in iNaturalist is different from the name used in the reference list of nonnative species. In the absence of taxonomic reconciliation, managers should

recognize that the resulting watch list may not include all nonnative species occurring in the buffer.

Although the method we present was tested on NPS units, the script could be used anywhere with both API access to georeferenced citizen science observations of the taxa of interest and a list of nonnative species. The method works on animal groups just as well as with plants. Observations from multiple citizen science schemes could be combined to increase the number of records available for detecting nonnative species. With no sign of abatement in the spread of nonnative species, tools such as the one we describe here can be important components of EDRR strategies to protect native ecosystems.

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Kris Barnes holds degrees from Hampden-Sydney College (BA) and Johns Hopkins University (MS). Kris is the lead for the Biodiversity Discovery program in the National Park Service. He and his team provide data management and analysis support to parks focusing heavily on citizen science applications.

Parker Hopkins received his BS in Environmental Studies from the University of Colorado at Boulder, completing his Honor's Thesis on the use of data from iNaturalist to monitor invasive species on National Park Service lands. Now working for the US Forest Service, Parker has also focused on citizen science and climate science methodologies with the National Park Service and NOAA.

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