REVIEW

Capacity of United States federal government and its partners to rapidly and accurately report the identity (taxonomy) of non-native organisms intercepted in early detection programs

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Abstract The early detection of and rapid response to invasive species (EDRR) depends on accurate and rapid identification of non-native species. The *2016–2018 National Invasive Species Council Management Plan* called for an assessment of US government (federal) capacity to report on the identity of non-native organisms intercepted through early detection programs. This paper serves as the response to that action item. Here we summarize survey-based findings and make recommendations for improving the federal government's capacity to identify non-native species authoritatively in a timely manner. We conclude with recommendations to improve accurate identification within the context of EDRR by increasing coordination, maintaining taxonomic expertise, creating an identification tools clearinghouse, developing and using taxonomic standards for naming and identification protocols, expanding the content of DNA and DNA Barcode libraries, ensuring long-term sustainability of biological collections, and engaging and empowering citizens and citizen science groups.

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Introduction

The United States government defines invasive species as, "with regard to a particular ecosystem, a non-native organism whose introduction causes, or is likely to cause, economic or environmental harm, or harm to human, animal, or plant health" and recognizes invasive species as a growing threat to a wide range of national values, including food and water security, infrastructure, and the environment, as well as plant, animal, and human health (Executive Office of the President 2016). The costs of these impacts to the US economy are already estimated in the tens to hundreds of billions of dollars per year and are expected to rise as new species are introduced and already established species continue to spread (Epanchin-Niell 2017; Pimentel et al. 2005). The implications are global; invasive species already in the United States pose risks to neighboring countries and trade partners (Paini et al. 2016; Reaser et al. 2003).

Minimizing invasive species impacts requires projecting and documenting non-native species occurrence (Reaser et al. 2019a, this issue), risk screening (Meyers et al. 2019, this issue), and timely and

effective management responses. Reaser et al. (2019a, this issue) provide a systematic framework for the early detection of and rapid response to invasive species (EDRR), defining it as a guiding principle for minimizing the impact of invasive species in an expedited yet effective and cost-efficient manner, where detection is the process of observing and documenting an invasive species, and response is the process of reacting to the detection once the organism has been authoritatively identified and response options assessed. We adopt this approach and provide this paper as a component of the assessment of US capacities for enacting EDRR described by Reaser et al. (2019a, this issue). Here, we explicitly respond to the *2016–2018 National Invasive Species Council (NISC) Management Plan* directive to assess "the capacity of the federal government and its partners to rapidly and accurately report the identity (taxonomy) of non-native organisms intercepted in early detection programs" (NISC 2016). Our findings are drawn from responses to a survey distributed to the federal agencies (Reaser 2019a, this issue), online research, interviews with agency staff, government reports, and peer-reviewed literature. Throughout the paper, we provide recommendations to improve taxonomic capacity for EDRR applications.

Assessment findings

Although there has been a culture of interagency support in the taxonomic identification of species and new technologies are speeding up taxonomic identification and making the overall process more cost-efficient, the federal government's capacity to identify non-native species in a timely and accurate manner needs substantial improvement. A complex set of federal, state, and other entities provide, or can potentially provide, taxonomic support for identifying invasive species and creating identification technologies, but discovering the identities and capacity of these entities is challenging. Many are collaborating at some level, but few clear Identification Process Chains (IPC; see below) exist, and some correspondents had problems locating these for reference. Developing a sustainable taxonomic/identification system to support a national EDRR program requires simplification, streamlining, greater collaboration, clarity on available capacity, and flexibility to adapt to changing

pressures. Above all, it needs to provide relevant identification as soon as possible after the detection to enable proper reporting and appropriate responses, thus playing a critical role in the comprehensive EDRR framework described by Reaser et al. (2019a, this issue).

The importance of identification and taxonomy for invasive species management

The importance of taxonomic support for invasive species identification has been emphasized globally (Davis Declaration 2001; Smith et al. 2008; Pyšek et al. 2013; Commission on Genetic Resources for Food and Agriculture 2019) and nationally (Meyerson and Reaser 2003; Chitwood et al. 2008; Diaz-Soltero and Rossman 2011; Buffington et al. 2018a, b). A general concern, also raised by federal agencies and individuals contacted in this study, is the diminishing availability of taxonomic expertise, arising from a decreasing number of scientists and changing priorities of laboratories (Meyerson and Reaser 2003; Stack et al. 2006).

The importance of correct, rapidly delivered identification cannot be overstated. The provision of a (scientific) name for an organism suspected to be invasive allows:

- clarity whether the organism is likely to be non-native;
- access to biological, ecological, pathway, and management information;
- determination of any county, state, or federally prescribed actions;
- unequivocal communication between stakeholders.

For example, in 2002 the "Rasberry crazy ant" (*Nylanderia fulva*) was reported in Houston, Texas. This proved to be very difficult to identify. Even getting specimens to taxonomists sufficiently expert in the group took too long. Identification was not confirmed until 2012 (Gotzek et al. 2012), by which time the species had spread considerably and caused massive damage.

Key scenarios requiring identifications

The circumstances in which a potential invasive species is detected have important implications for

the problems faced in its identification and the personnel engaged in the Identification Process Chain (IPC; see below), and thus capacity requirements. Two non-exclusive axes can be used to explore this matter (Fig. 1).

Axis 1: Targeted cf. General inspections. Targeted inspections and monitoring activities focus on one or a few key species (e.g., Asian hornet [*Vespa velutina*] in the United Kingdom [Gov.uk 2017]). General inspections, such as BioBlitzes (Silvertown 2009; Looney et al. 2016; Doing it Together Science 2017), will expose the inspection team to a very large number of species, which may or may not be actually or potentially invasive.

Axis 2: Pathway cf. Site inspections. Pathway inspections screen for actual or potential invasive species in the context of a pathway (e.g., solid wood packaging at Ports of Entry [PoE], trailered boats through state-line inspections; see Liebhold et al. 2006, 2012; Jenkins et al. 2014) and site inspections survey the area within a larger recipient ecosystem where invasive species might be detected (e.g., National Parks, agricultural extension).

The two axes operate together, for example targeted inspections are most effectively carried out as a result of risk assessments that highlight particular pathways (European Environment Agency 2010; Poland and Rassati 2019). A strategic framework for surveillance
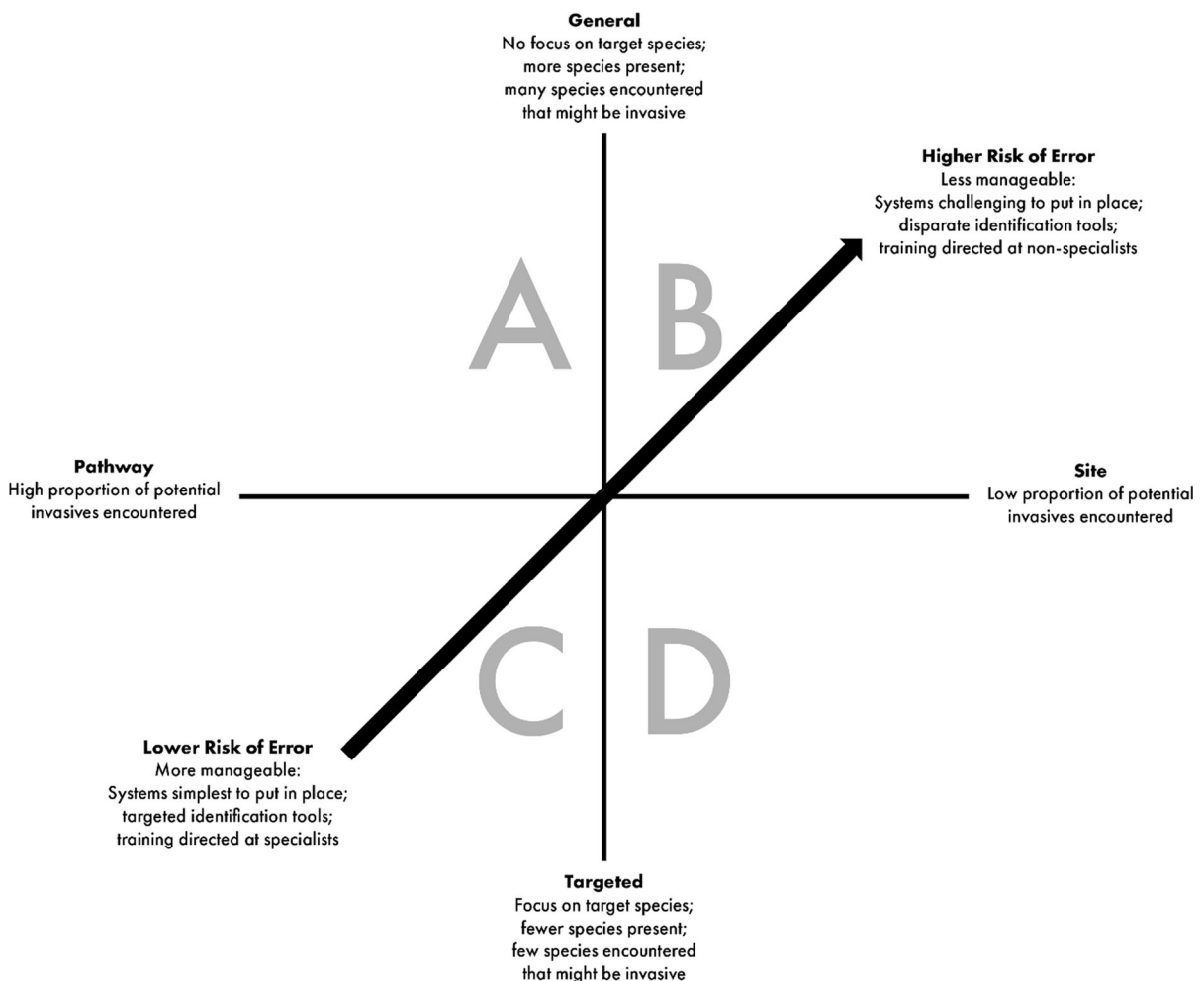
Fig. 1 Identification scenarios. The greatest management challenges and highest risk of error are in the top right, the most sustainable management possibilities in the bottom left. The background letters are for reference in the text

can consider the nuances and caveats for PoE vs recipient ecosystems (Morisette et al. 2019, this issue).

Targeted species (Fig. 1 quadrants C and D)

Targeted species inspections are most likely to feature a relatively high proportion of target to non-target observations (non-invasive species that might be confused with invasive species), many repeat observations, a geographically fixed base, and long-term staff or citizen science engagement. These allow focused identification technologies; staff training and expertise build-up in the use of sampling equipment and identification technologies; sensitization to target species; strong, formalized and short Identification Process Chains with high potential for rapid response; and minimized risk of error. For example, the US Fish and Wildlife Service (USFWS) uses eDNA to detect invasive carp in the Great Lakes (Jerde et al. 2013; Mahon et al. 2013; falling in quadrant D), and the federal and state agencies have collaboratively developed methods to detect brown tree snakes at points of entries (Clark et al. 2018; falling in quadrant C).

Pathway inspections (Fig. 1 quadrants A and C)

PoE Pathway inspections feature trained staff and rapid IPCs, either through local Plant Inspection Stations (US Department of Agriculture 2017a), or through US Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) National Identification Service (APHIS 2015), Centers for Disease Control and Prevention (CDC 2013), or USFWS (USFWS Office of Law Enforcement 2017). US Customs and Border Protection (CBP) Agriculture Specialists are trained to identify pests and diseases, but their preliminary identification has to be confirmed by a USDA entomologist or plant pathologist. APHIS has a rapid (24 h) identification system in place (at least where taxon specialists are available). CBP Agriculture Specialists and others at PoE are supported by specialist identification technologies (USFWS 2010; APHIS 2017a).

State Line Pathway inspections are particularly important for states with significant agricultural industries such as California and Florida, where inspection agents can send interceptions or photographs to taxonomists in a formal system (California Department of Food and Agriculture 2018a). A special

case is watercraft inspections, where detection of biological material alone may suffice to require decontamination and individual organisms may not need to be identified.

General and site inspections (Fig. 1 quadrant B)

General and site inspections pose the most challenging model for capacity. Often they are handled regionally, with variable integration between regions (e.g., USDA's National Institute of Food and Agriculture [NIFA]'s Crop Protection and Pest Management Program (CPPM) [NIFA n.d.], USFWS regions), or between sites (e.g., DOD lands, National Park Service [NPS]). DOD manages invasive species under local Integrated Natural Resources Management Plans (INRMP) liaising with the USFWS, but with no national coordination. The number of possible species and the larger areas involved pose a problem. Allen et al. (2009) report 3756 different non-native plants in US National Parks with a maximum of 483 non-native species from one park, and more than 120 National Parks contain 50 or more non-native species (Stohlgren et al. 2013). Agriculture is perhaps better served than natural areas, with the APHIS Cooperative Agricultural Pest Survey (CAPS) Program (NIFA n.d.), which carries out national and state surveys targeted at specific exotic plant pests, diseases, and weeds identified as threats to US agriculture and/or the environment, much of which operates at the state level through the Cooperative Extension System (CES).

General and site inspections are likely to feature an unknown and potentially large number of target species, a relatively low proportion of target to non-target observations; few repeat observations; intermittent inspections without a fixed base for staff; and short-term observer engagement with involvement of amateur and ad-hoc observations. These lead to employment of many identification technologies of mixed quality; fewer opportunities for staff training and building expertise; weak or ad-hoc IPCs; and higher risk of not identifying potential invasive species at low density. Rapidity in the flow of information is also more challenging. Strategic efforts on target analysis and detection (Morisette et al. 2019, this issue; Reaser et al. 2019a, this issue) can help address these challenges, but equally important is investing in proper taxonomic identification.

Building a sustainable taxonomic resource to support EDRR

A sustainable taxonomic resource includes capacity both of people and the resources they use (Table 1). Crucially, all elements must be present and available; lack of taxonomists removes the most authoritative layer and precludes identifying many interceptions, while loss of citizen science input may make general site surveys impossible. Taxonomists and other identifiers require collections and identification technologies, and all stakeholders must have access to the same lists of species names. Not only must all of these elements be present, but the personnel (and those detecting possible invasive species and seeking identifications) must be efficiently connected through an IPC. Different aspects of a sustainable taxonomic resource may be preeminent in EDRR activities in different quadrants of Fig. 1, but the whole structure is required for any of it to be fully operational. For such a system to function there has to be some oversight and responsibility for maintenance, or at least a central resource or portal where information and contacts can be shared. This should be a facet of whatever coordination mechanism is implemented for any national EDRR framework.

This taxonomic resource capacity cannot exist in isolation, and it will operate in response to its users' requirements. Federal bodies and users of invasive species identification expertise or technologies should therefore consider their requirements and how they are met, and ask themselves:

1. Is the current expertise supply sufficient and subject to management? (Any expertise based on retired specialists or being provided on an ad hoc basis is not within the management capacity of the body.)
2. Are high-risk groups of organisms of key importance covered taxonomically (see Reaser et al. 2019b, this issue)?
3. Where will expertise and supply of identification technologies (see Martinez et al. 2019, this issue) come from in 5 years' time? (Taxonomists take time to train and recruit, and a succession plan is needed to ensure that at least high-priority groups are covered).

Identification process chains

In the context of EDRR three key stages can be considered as forming an Identification Process Chain (IPC): detection (interception, screening, collection, etc.), identification, and reporting (receipt of identification by the management authority) (Fig. 2). Table 2 gives recommendations to establish and improve IPCs. The IPC described here provides additional details among the detection, identification, and reporting components of the EDRR framework from Reaser et al. (2019a, this issue).

Failure to have an authoritative IPC can have serious consequences, as with a case of *Drosophila suzukii*, the spotted wing *Drosophila*. Here, following an incomplete identification from local experts, a farm advisor used a web search engine to locate an expert. Unfortunately this person was not a taxonomist and the identification was incorrect, hindering response (Hauser et al. 2009; Hauser 2011). The IPC should be rapid and effective (Stack et al. 2006). It should be managed so that both specimens and necessary information are transmitted along it and all individuals know procedures to follow and the priority of the submission. The more complex the chain the longer the identification process (Smith et al. 2008), the greater the chance for miscommunication, and the less it is fit for EDRR.

IPCs differ between agencies and even different regions or staff within a single agency, and they may not be formalized or widely understood. Almost every agency responding to the NISC survey, and many individuals contacted, called for stronger linkages between those intercepting possible invasive species and sources of taxonomic expertise. Members of established networks, such as the National Plant Diagnostic Network (NPDN; Stack et al. 2006; https://www.npdn.org, accessed 12 March 2019), National Animal Health Laboratory Network (APHIS 2017b), and the Wildlife Health Information Sharing Partnership event reporting system (WHISPers) may, through their interactions, facilitate a sample reaching the appropriate expertise. However, unless this is built into a formal system of sample transfer, the potential of network membership may not be fully realized. Collaboration is an important component of invasive species management (Davis Declaration 2001) including EDRR, and may facilitate locating expertise. Collaboration between CBP, USDA, CDC and

Table 1 Actors, their roles, and the resources necessary for the actors to carry out their tasks in a sustainable taxonomic framework

Actors	Roles				Key resources used				
	Research—establishing species concepts; correct names to use	Generating identification technologies	Identifications	Compiling authoritative lists of names	Collections	Laboratories, including DNA	Lists of names	Identification technologies	Other literature resources
Further detail provided in Tables below		Table 2			Table 5 Table 7		Table 8	Table 6 Table 7	
Taxonomists (Table 3)	*	**	*	**	*	*	*	*	*
Expert identifiers (Table 3)		*	*		*	*	*	*	*
Database managers				*			*		*
Citizen scientists (Table 4)			*				*	*	*
Other interception and survey personnel			*				*	*	*

An effective EDRR will require all actors and resources, appropriately targeted. Reference is made to Tables below where the role or resource is further analyzed

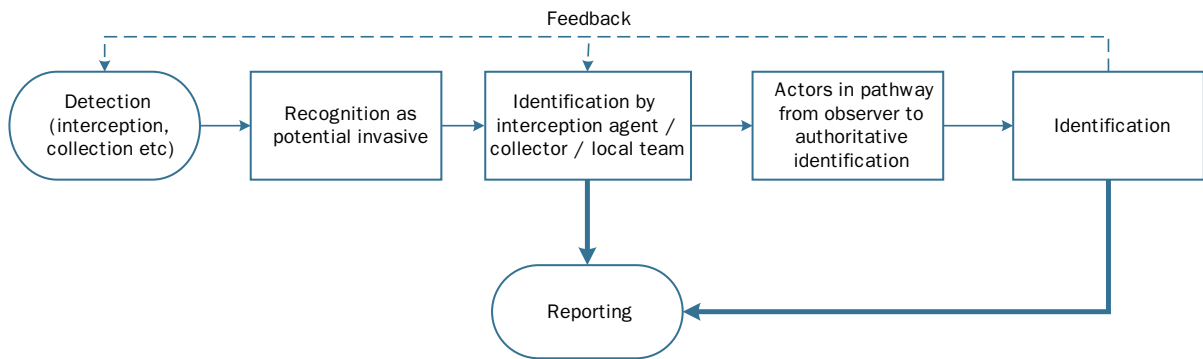**Table 2** Identification process chains: recommendations

IPC—aspects hindering rapid identification	Actions to increase rapidity
Experts difficult to locate	I. NISC
	1. Establish EDRR Coordination Mechanism ("EDRRCM"), perhaps by expanding role of NISC Secretariat
	II. EDRRCM, working with federal and state agencies
	1. Develop and enhance IPCs for EDRR procedure
	a. Create and use lists of experts
	b. Encourage MOUs between stakeholders including experts to
	i. Develop formal networks and IPCs
	ii. Ensure timely availability of experts
	c. Engage established networks/IPCs to participate in national EDRR
	III. Established networks to facilitate IPCs by improving linkages
Experts working for unconnected organizations	I. EDRRCM
	1. Develop mechanism to assist partnerships
	II. Individual agencies and organizations
	1. Increase collaboration, with formal MOUs where possible
	III. Agencies managing IPCs
	1. Consider opening them to other agencies where appropriate and necessary to facilitate identifications in EDRR
Experts in distant localities	I. Agencies managing site inspections
	1. To increase efficacy of expertise on site
	a. Use professional identifiers at fixed sites
	b. Make use of trained citizen scientists
	c. Increase use of appropriate identification technologies
	d. Work with established networks/IPCs
	II. Various stakeholders
	1. To improve rapidity of IPCs
	a. Site managers to establish preliminary identifications where possible to facilitate transmission to relevant expert through IPC
	b. Users send images (noting that in many cases specimens may be necessary for a precise identification)
	c. EDRRCM to recommend targets for rapidity of transmission
	d. EDRRCM to work with agencies to develop and emplace standard reporting and specimen transmission system

USFWS on PoE is a strong example. Department of Defense (DOD) and the USFWS work together on DOD lands, and the Great Lakes Restoration Initiative involves collaboration among USFWS, Environmental Protection Agency (EPA), and USGS.

Federal agencies operating without a national framework to engage with taxonomic capacity may rely more on local expertise. When this is insufficient, individuals may have difficulty locating the appropriate resource or finding an established IPC appropriate to the species in question. Not all IPCs are open to all agencies, and few online expert directories exist. USDA provides suggestions on which labs should receive identification requests (APHIS 2017c). The Aquatic Nuisance Species Task Force maintains an Experts Database by state (USFWS n.d.), including taxonomists. The page also carries links to the Delivering Alien Invasive Species Inventories for

Fig. 2 Identification Process Chain (IPC) from observation to identification and from identification to management. Feedback may assist future identifications

Europe (DAISIE) expert search (http://www.europe-aliens.org/, accessed 12 March 2019) and to US systems that no longer exist: the National Oceanic and Atmospheric Administration's (NOAA) Taxonomic Cadre and the National Biological Information Infrastructure's (NBII) Taxonomic Resources and Expertise Directory. NBII has been off-line since 2012, at least partially because of budget cuts (USGS 2011), although some elements were later covered by BISON (Biodiversity Information Serving Our Nation). Some professional societies maintain membership lists (e.g., American Society of Plant Taxonomists Membership Directory; https://members.aspt.net/civicrm/profile?gid=25&reset=1, accessed 4 October 2018), but with no guarantee of completeness or expertise. USDA has a web-based search tool for connecting researchers with peers, although it does not search for taxonomists (USDA 2017b). Adoption of Open Researcher and Contributor Identification (ORCID) by taxonomists may also assist in their location (Page 2018).

The rapidity of response in an IPC can be increased by local identification capacity in any of the quadrants in Fig. 1, facilitating finding the appropriate specialist. An example is Preclearance Inspections conducted in some countries exporting to the United States, performed under direct supervision of qualified APHIS personnel (USDA n.d.). USDA preclearance manuals (USDA 2011, 2012a, b, 2013, 2014a, b, 2015) mostly do not include identification aids, although USDA (2011) shows images of bulbs attacked by pests or pathogens, and USDA (2012a) has rather crude line drawings and some photographs (but they do not indicate diagnostic features). Increasingly, image-based systems allow rapid submission and transfer, so the specialist can see the specimens sooner, although images are more effective for some organisms than others (G. Miller, L. Chamorro pers. comm).

Shippers are required to identify plants (and are provided with lists of names), but there is no guidance on technologies or taxonomic standards that should be used. Taxonomic skills and resources in other countries may be absent, so identifications associated with imports to the United States may not be possible, or they may employ different taxonomic concepts and names. While there is no guarantee that the identification given matches US concepts, this is subject to checking at APHIS Plant Inspection Stations (USDA 2007) and may speed the process.

Expertise and infrastructure

Identification at the point of interception may simply recognize that a potential invasive is present and requires authoritative review, or may provide a preliminary or final identification. Local capacity to deliver this identification is built on informal or formal training and appropriate identification technologies. If identification is not possible locally to the appropriate confidence level, greater taxonomic expertise may be sought in state and federal bodies, such as laboratories maintained by the USDA Agricultural Research Service (ARS), the CDC, and the Smithsonian Institution (SI), and many state universities, although engaging such an entity may lengthen the IPC. Professional taxonomic expertise is required for the most authoritative identifications, to develop and maintain identification technologies, and to manage

Table 3 Expertise: recommendations

Expertise—aspects hindering rapid identification	Actions to increase rapidity
Expertise for authoritative identifications unavailable	I. All bodies employing taxonomists
	1. Increase support for systematics and taxonomy, both for native and especially invasive species.
	2. Develop identification expertise in life stages of organisms where no identification technologies exist
	II. Federal agencies
	1. Plan for necessary taxonomic expertise to be available within an EDRR structure
	2. Develop efficient means to make use of taxonomists outside the US where expertise is lacking. A model might include Australian Biological Resources Study (ABRS)'s grant program supporting projects facilitating areas that will boost Australia's taxonomic capacity
	3. Consider co-funding expert positions
Professional identifiers unavailable	I. Federal agencies
	1. Recruit additional inspectors at PoE
	2. Develop expertise to support identifications at regional level
	3. Develop training programs for personnel at field and laboratory level, covering identification of known and potential invasive species, particularly understanding of techniques, resources, and technologies
	4. Build training programs into management systems to ensure that skills are regularly refreshed
	II. Government
	1. Ensure funding to federal agencies to contract identification support, including use of eDNA
Identifications slow	I. Federal agencies and the EDRRMC
	1. Develop incentives such as grants to develop identification technologies, revise high-priority problematic taxa, and support taxonomic databases
	II. Laboratories
	1. Train and recruit technicians to improve speed with which samples are processed and analyzed

See Table 1 for relevance to a sustainable taxonomic resource for EDRR

the contents of taxonomic databases. Availability of such expertise in a timely manner needs to be planned and managed (Smith et al. 2008). Federal bodies do not supply identification and taxonomic expertise to manage all current requirements for confirming invasive species occurrence; a strategic national EDRR program would provide an opportunity to review and build such capacity efficiently across federal and state agencies, universities, and private companies.

Current trends may indicate projected needs. USDA Systematic Entomology Lab (SEL) identification requests from PoE (each of which might include multiple specimens and species) rose from 9624 in 2004 to 17,755 in 2010, the "urgent" requests from 3572 to 8469 in the same period (A. Solis pers. comm); in 2016 SEL received 30,000 specimens for identification (G. Miller pers. comm). Each day CBP intercepts around 470 plant pests and diseases (Harringer 2016) and seizes around 4548 prohibited plant materials and animal products. Work et al. (2005) suggested that port interceptions were not finding all species, suggesting an insufficient inspection rate and potentially higher identification requirements. An increased detection rate within an EDRR system will increase calls for identifications. Recommendations

relating to availability of suitable expertise are given in Table 3.

Expertise availability

Many correspondents stated that obtaining identifications was very time-consuming or impossible. Lack of experts—generally professional taxonomists—appears to be a major problem. Professional taxonomists as discussed here are people who devote a significant part of their work to describing species or carrying out other taxonomic research. The number of such professionals in the United States or globally is unknown. There is general agreement that the number of taxonomists and positions for taxonomists is decreasing (Davis Declaration 2001; Mikkelsen and Cracraft 2001; Agnarsson and Kuntner 2007; Chitwood et al. 2008; Drew 2011; Hauser 2011; Wild 2013; Foottitt and Adler 2017; Wilson 2017). There is an acknowledged shortage of suitable staff in some areas such as field pathology (Miller et al. 2009; Stack 2010), and federal staff in a number of agencies interviewed in preparing this paper reported a lack of taxonomists available for some groups such as grasshoppers and mites. Retired staff are often relied upon; the National Museum of Natural History (NMNH) Entomology Staff directory lists more emeritus personnel, associates, and collaborators than employed researchers. Emeritus personnel alone constitute half as many as currently employed researchers. In the 1970s the SEL had 29 scientists, while it now has 15; SEL does not accept non-urgent identification requests for some taxa (although it sends some non-urgent enquiries to external collaborators when staff are unavailable; G. Miller pers. comm; ARS 2016). In addition to personnel loss, the strong but unofficial peer-to-peer networking is now breaking down as people retire or leave the field.

Perhaps most identifications are undertaken by non-taxonomists employed to identify invasive species, particularly in quadrants A and C in Fig. 1. Key examples are PoE interception staff and employees of agencies supporting other pathway inspections. These government personnel can be regarded as professional identifiers. Most CBP Agriculture Specialists hold a bachelor's or higher degree and have taken a 12-week training course from USDA including pest and disease identification and quarantine regulations, supported by port-specific, post-academy training. There are ca.

2400 CBP Agriculture Specialists at PoE (Lapitan 2016; Harringer 2016), staffing approximately half of the 329 PoE. CBP has reported a shortage of such experts in key high volume PoE, but CBP's Agriculture Program and Trade Liaison (APTL) has developed a dynamic "Agriculture Resource Allocation Model" to address staffing needs based on quantifiable volume and pest risk (M. Atsedu pers. comm). Other federal agencies also have identification skills amongst their staff, although they too report lack of taxonomic expertise at site and regional levels.

Existence of expertise does not guarantee EDRR capacity. The job duties of a taxonomist may not allow time for identifications, or identifications outside of a particular scope (Lyal and Weitzman 2004; Wild 2013). Taxonomists' activities are determined by their institutional and funders' priorities. Experts may also need time to develop their expertise, prepare identification technologies, and revise the taxonomy of problematic groups. That such research is important is exemplified by the story of the Rasberry crazy ant in Houston, where different opinions and a very difficult taxonomic problem delayed effective management and permitted spread of the species (Gotzek et al. 2012; Wang et al. 2016). Consequently, merely evaluating the number of taxonomists in post gives limited information on relevant capacity for EDRR. The declining number of taxonomists inevitably has a negative impact on identification capacity, and any solution must involve both increasing taxonomist numbers and their availability for effective EDRR. Mapping invasive species risk profiles against identification capacity will inevitably reveal gaps both currently and as the potential invasive species pool changes [e.g., SEL does not cover some insect groups, such as grasshoppers, except when urgent (ARS 2016)].

No nation has sufficient taxonomic expertise to support identifications of all of their biota (Secretariat of the Convention on Biological Diversity 2007). Effective coverage of global biodiversity is even more challenging and expertise is widely dispersed globally (Smith et al. 2008). The nature of invasive species means that relevant taxonomic expertise may lie in their countries of origin outside the United States, and information may have to be sought from these specialists; international networks and contacts are required (Davis Declaration 2001; Stack and Fletcher 2007; Stack 2010). This requirement can pose

Table 4 Citizen science: recommendations

Citizen science—aspects hindering rapid identification	Actions to increase rapidity
Too few citizen scientists engaged	I. All agencies and the EDRRCM
	1. Increase understanding that the role of citizen science in management of invasive species is integral to future success, including to aquatic systems (USFWS 2015)
	2. Enhance citizen science programs, including
	a. Public awareness activities
	b. Outreach to selected groups
	c. Recruitment program
Identifications not of appropriate quality	I. EDRRCM, working with federal agencies
	1. Develop and implement identification protocols
	2. Develop and implement training systems, including on the use of identification technologies and the capacity to provide suitable information to the appropriate authorities who can take action
	3. Develop and implement appropriate management techniques for citizen science reports, including data quality

See Table 1 for relevance to a sustainable taxonomic resource for EDRR

problems that need resolution: locating experts; response time; management of experts; ability of a federal agency to issue a contract to pay for identifications; and impediments in sending specimens between countries from Access and Benefit-Sharing regulations (McCluskey et al. 2017).

Engagement of amateur communities can be more cost-effective than employing researchers and produce more rapid identifications in cases of easily identified invaders (Goldstein et al. 2014; Lodge et al. 2016; Looney et al. 2016). Citizen science is perhaps most required in quadrants B and D of Fig. 1. Some citizen science groups are very local in their activities, benefitting from familiarity with local fauna and flora and sensitivity to unfamiliar species. Groups might be encouraged to develop citizen science skills and engage in invasive species monitoring, even if they would not self-identify as being first responders. For example, existing interest in conservation photography among nature photographers (North America Nature Photography Association 2017) could be harnessed to submit high-quality images with GPS data to appropriate systems. The UK Riverfly Partnership (http://www.riverflies.org, accessed 12 January 2018) comprises conservationists, entomologists, scientists, water course managers, and relevant authorities, working together on aims centered around conservation. In the United States, streamkeepers and others already monitor for invasive species (Johnson 2014), and a wider partnership could be developed with citizen scientists. Citizen scientists may not be able to provide information with as consistent a level of reliability as specialists (Newman et al. 2010; Lewandowski and Specht 2015), and accuracy may decrease with rarer encounters (Swanson et al. 2016). Reliability is improved with appropriate training (Newman et al. 2010; Gardiner et al. 2012; Freitag et al. 2016) and observation and analysis protocols (Tweddle et al. 2012). Most if not all states have Master Gardener and Master Naturalist programs, and Collaborative and Enhanced First Detector Training programs exist at the state or network level, e.g., by the National Plant Diagnostic Network (NPDN n.d.) and Bugwood (Hummel et al. 2012). These programs increase understanding of relevant agency responsibilities, including the appropriate IPC to bring specimens to specialists (Stubbs et al. 2017). Recommendations for mobilizing and managing citizen science engagement with EDRR processes are given in Table 4.

Collections

Biological collections, including museum, herbarium, and culture collections, are a key resource to support rapid identification of invasive species and provide

Table 5 Collections and laboratories: recommendations

Collections and laboratories—aspects hindering rapid identification	Actions to increase rapidity
Collections at risk of loss, or inaccessibility through lack of staff	Agencies with scientific collections
	Ensure support for long-term sustainability of collections for invasive species activities (Miller 1991; Pape 2001; Entomological Society of America 2016)
Specimens for comparison unavailable	Collection-holders
	Ensure they have holdings of relevant native and possible invasive species
Specimens for comparison incorrectly identified	Collection-holders
	Take steps to confirm the identity of invasive species in their collections
Diagnostic laboratory capacity insufficient	Relevant stakeholders
	Ensure sustainable funding for federal and other public laboratories to provide identification and diagnostics. Funding as research bodies rather than identification services will attract desirable levels of expertise

See Table 1 for relevance to a sustainable taxonomic resource for EDRR

information on distribution, origin, and biology, etc. (Simpson 2004; Suarez and Tsutsui 2004; Smith et al. 2008; Interagency Working Group on Scientific Collections 2009; Gotzek et al. 2012; Lavoie 2013); they also provide material to develop molecular technologies (Hubert et al. 2008; Galan et al. 2012). To meet these needs, relevant collections must hold examples of both native and non-native species to enable comparison, and specimen identifications in those collections need to be correct; this cannot be assumed (Goodwin et al. 2015; Jacobs et al. 2017; Sikes et al. 2017). Observations, molecular technologies, and DNA sequences should be vouchered by physical specimens in collections (Ratnasingham and Hebert 2007; Packer et al. 2018). Appropriate federal collections exist for vertebrates, invertebrates, and plants. Culture collections have a less clear model. USDA maintains several culture collections, including ARS (2017) and Ft. Dietrich for invasive species. The American Type Culture Collection (https://www.lgcstandards-atcc.org, accessed 4 October 2018) charges for deposit and retrieval, and consequently some researchers send strains overseas (K. McCluskey pers. comm). Despite initiatives such as the US Network of Culture Collections (McCluskey et al. 2017) there is poor US infrastructure for microbial collections, with problematic funding support (Smith 2017).

The last detailed survey of US systematic collections was 1988, with publications on insects (Miller 1991), fish (Poss and Collette 1995), and mammals (Hafner et al. 1997). Gropp and Mares (2009)

predicted funding issues in the Natural Science Collections Alliance 2008 survey of North American (federal and non-federal) collections. While most federal collections are growing, there have been problems with declining numbers of trained staff and funding resources (IWGSC 2009). Information on global scientific collections is available online (https://www.gbif.org/en/grscicoll accessed 10 July 2019). Non-federal collection-holders include private bodies and non-governmental bodies such as universities. Unlike federal collections, for which proper care is required by Public Law 111-358 section 104, there is no guaranteed sustainability. For example, the University of Louisiana at Monroe recently disposed of its collection of ca. six million fish and half a million native plants. As with federal collections, declining staff numbers are an issue (Kemp 2015). Recommendations for collections in the context of EDRR are given in Table 5.

Laboratories

Federal, public, and private laboratories provide diagnostics and identifications of whole organisms, micro-organisms, or fragments (Trebitz et al. 2017). Some are operated by collection-holding institutions, others by federal agencies (e.g., USDA's Center for Plant Health Science and Technology (CPHST) Beltsville laboratory). Both animal and plant diseases are served by networks of laboratories (APHIS 2017b; https://www.nahln.org, accessed 2 October 2018;

https://www.npdn.org, accessed 12 March 2019). Both California and Florida have large State Department of Agriculture laboratories that identify agricultural organisms, while some other states maintain smaller laboratories. No information is available to assess whether the capacity of the extant laboratories suffices for an EDRR program, although NPDN and USDA's National Animal Health Laboratory Network operate in a competitive funding environment, and the use of private facilities suggests insufficient federal capacity. Recommendations for laboratories in the context of EDRR are given in Table 5.

Identification technologies

The rate at which species are identified can be increased by making identification technologies more readily accessible (all quadrants in Fig. 1). Martinez et al. (2019, this issue) provide a broad, but selective, overview of advanced technologies for achieving EDRR. Below we touch on those technologies identified by the federal agencies as being particularly important for non-native species identification. Identification of some groups relies particularly on one life stage, and absence of this stage limits or prolongs identification, especially if no taxon experts are available (Hauser et al. 2009; Hauser 2011). Thus, although many insects can be identified only from adults, approximately half of submissions to SEL are immature. Specific identification technologies may address this problem [e.g., on intercepted Lepidopteran larvae (Gilligan and Passoa 2014; LeVeen 2014)]. Recommendations related to identification technologies are given in Table 6.

Molecular technologies

Molecular technologies permit rapid non-specialist identification (Hubert and Hanner 2015). Use of DNA barcodes (Rugman-Jones et al. 2013) or eDNA (Wilcox et al. 2015) makes it possible to detect and identify invasive species effectively and to a rigorous standard (Frewin et al. 2013), and eDNA allows detection even when only few specimens are present in the environment sampled and none have been captured or seen. Use of DNA barcodes at PoE may facilitate rapid identification of immature stages of insects, and it could be incorporated into border security programs as an adjunct to morphological identification (Madden

et al. 2019). Increasing use of DNA barcodes may reveal unnamed cryptic species (Weissman et al. 2012; Jaric et al. 2019), which can be referred to by the Barcode Index Number (BIN) system (Ratnasingham and Hebert 2013; Miller 2015). However, names will be required to relate these to extant information, requiring expertise from a taxonomist (Sheffield et al. 2017). DNA use is evolving rapidly (e.g., Ardura et al. 2017; Wilkinson et al. 2017; Roe et al. 2019; Bilodeau et al. 2019). However, more papers test new methods for potential value in invasive species detection than report their adoption as embedded systems.

Use of molecular data relies on a library of DNA sequences (DNA barcodes, other selected genes, or genomes) to identify sequences from unknown organisms. Although large, these libraries are incomplete (Adamowicz et al. 2017; Curry et al. 2018); Wilkinson et al. (2017) estimate that Barcode of Life Data System (BOLD) holds core DNA barcodes for only 15% of land plant species, and intraspecific coverage is even less complete. Some groups have more than 90% coverage for an intensively-sampled area (Zahiri et al. 2017) but may omit non-native species (Hauser 2011). Many correspondents expressed the importance of a global barcode library (D. Lodge, J. Pecor pers. comm), with a priority given to pest species, particularly those with a high likelihood of invasion. For example, the Walter Reed Biosystematics Unit is building a BOLD database of mosquitoes and other disease hosts. Expanding coverage and improving quality may require development of new technologies (Wilkinson et al. 2017) and priorities (Madden et al. 2019). Moreover, ongoing quality assurance and control of identifications in DNA libraries is needed, including re-assessment on addition of new sequences and with taxonomic changes (Curry et al. 2018).

Genetic markers for eDNA also need further development, especially for novel invasive species, and those already developed may not be widely known. Obtaining samples of target species from outside the United States can be difficult and leads to prioritization of easily-obtained species (Great Lakes USFWS team, pers. comm). Increasing sensitivities in many countries around Access and Benefit-Sharing (Secretariat of the Convention on Biological Diversity 2017) and the use of digital sequence information will need to be managed effectively to facilitate obtaining such samples.

Table 6 Identification technologies: recommendations

Identification technologies—aspects hindering rapid identification	Actions to increase rapidity
Insufficient non-molecular technologies for widespread use	I. Federal agencies, universities and research bodies
	1. Develop technologies for professional and citizen science use, including apps to cover all priority invasive species that can be identified using these methods, making them site-appropriate where needed
	2. Prioritize development of non-molecular or molecular technologies to support identification of regularly intercepted problematic life stages
Technologies may not be of appropriate quality to produce accurate identifications	I. EDRRCM
	1. Encourage development of and promote standards for technologies such as apps
	2. Develop resource list of technologies meeting standards to increase availability, with reviews of their suitability for different taxa and geographical regions
	II. Stakeholders producing apps and other technologies
	1. Adopt standards proposed by EDRRCM
Sequence libraries incomplete	I. Federal agencies, universities, research bodies, relevant database owners and collection-holders
	1. Expand authoritative vouchered genetic sequence libraries
	a. Complete a global DNA barcode library
	b. Develop eDNA markers for high priority species
	c. Ensure availability of tissue samples from reliably identified and uncontaminated voucher specimens. Facilitate sourcing specimens from outside the US, including managing ABS regulation requirements
	d. Prioritize pest species for future DNA library entry and data quality re-evaluation, particularly those with a high likelihood of invasion
Sequencing facilities and expertise insufficient or unavailable	I. Federal agencies
	1. Foster collaborations and partnerships between each other and internally to increase access to sequencing and bioinformatics capabilities
	2. Increase access to bioinformaticians, bioinformatics analysis programs and database development by their staff
	3. Invest in hardware to expand sequencing efforts

See Table 1 for relevance to a sustainable taxonomic resource for EDRR

DNA methods have limitations. Different genes, even "DNA barcodes," perform at different accuracies (Braukmann et al. 2017; Wilkinson et al. 2017). Assays differ in resolution (Amberg et al. 2015), and next-generation sequencing may provide a higher resolution than Sanger sequencing (Batovska et al. 2017). While many studies report over 95% accuracy, claims of 100% accuracy have not been seen. Some taxa have not proven amenable to determination using barcodes (Piredda et al. 2010; Pyšek et al. 2013). While accuracy and rapidity in detection are improving, this does not automatically lead to field use. Variation in results obtained using different methods and continual methodological changes might limit acceptance (D. Lodge, Great Lakes USFWS team pers. comm). Federal agencies with diagnostic standards may require careful evaluation and official approval of methods (e.g., US Food and Drug Administration 2017a). Despite this requirement, many federal agencies are using DNA-based techniques and even extending them, e.g., USGS with eDNA detection kits for Asian carp (Great Lakes USFWS team pers. comm). Using eDNA technologies to detect the presence of sea lamprey in the Great Lakes is under development (Gingera et al. 2016). An issue with expanding sequencing work is the volume

of assays possible. USGS has three sequencers with capacity to produce more than 800,000,000 reads in less than 48 h; owing to the large volume of data generated, they have had to invest in infrastructure to store and process them. Increasing use of sequence data will inevitably cause such costs to rise. Correspondents stressed that much of the eDNA work was scalable but would take additional funds to roll out further.

Open technologies for general use

There are many identification technologies, including literature (field guides, dichotomous keys, identification cards, etc.), web sites, and smartphone apps. While the number of apps is increasing, they are insufficient to address all species that might be prioritized. Furthermore, the many web-based resources vary considerably in quality, can be difficult to locate, and may not include all species that might be intercepted (Stack et al. 2006); user assumptions that everything is included may lead to false positives. State-level coverage varies, but because of differing biota it is problematic to use an app developed for one state in another. There is no overall plan to ensure all priority invasive species are covered at the appropriate geographical level, nor is there a means of quality assessment. Identification technologies may be tailored to pathway or targeted inspections (Fig. 2 quadrant C) or general use (Fig. 2 quadrant B), although priorities for the former may be easier to set than priorities for the latter.

Although images do not ensure accurate identifications (Austen et al. 2016), their use can be extremely important (Vásquez-Restrepo and Lapwong 2018; Iwane 2018). Accuracy of image-based identification requires good images, clearly marked diagnostic features, and comparison with similar native species (e.g., Tsiamis et al. 2017). Comparing images of different species facilitates identification, but some systems do not allow this (e.g., http://www.invasive.org, accessed 4 October 2018; iNaturalist 2017). Images not indicating diagnostic features between similar species may lead to errors (Vantieghem et al. 2017). Technologies focusing on relatively easy-to-identify groups such as bumblebees, ladybirds, etc. may function well, but visual-based technologies are inappropriate for more cryptic, less well-marked, or smaller species.

Some quality control systems are in place for images. iNaturalist requires two matching identifications for an image before providing the image and data externally (G. Guala pers. comm). Increasingly, use of image recognition systems will have a role in species identification. However, currently USDA and other federal agencies might not accept technologies such as iNaturalist because there are not sufficient quality assessments, although the National Park Service uses iNaturalist with proper caution and awareness. There is no US equivalent to the Australian PaDIL (http://www.padil.gov.au, accessed 2 October 2018), which provides images and characters for a wide range of exotic organisms in its "Plant Biosecurity Toolbox."

Reliability measures

Responses to reported invasive species are potentially costly and likely to be triggered only when sufficient evidence is available from a risk assessment (Meyers et al. 2019, this issue), including identification reliability. This can be assessed by (1) reliability (authority) of the identifier; (2) reliability of the diagnostic laboratory; and (3) identification method. Although standards provide a measure of assurance, every system carries a risk of false positives or false negatives. An EDRR system needs a means of assessing identification reliability to determine response, balancing the risk of taking action when the identification reliability is not 100% against risks attendant on increasing time through seeking maximum reliability. Setting identification standards will assist this judgement. Recommendations for standards to improve reliability assessment and control are given in Table 7.

Identifier authority and accuracy

There is little clarity on requirements for recognized identifier expertise, and criteria will differ along the IPC. CBP Agriculture Specialists must have their identifications checked by a relevant authority. Since PoE interceptions may have legal consequences, identifiers might have expert witness status (although court appearances are rare for ARS taxonomists [G. Miller pers. comm]). Taxonomists do not have a certification system; instead they are judged on qualifications, publications, and experience. Overall there are likely to be limited options to standardize

Table 7 Standards: recommendations

Standards—aspects hindering rapid identification and response	Actions to increase rapidity
Uncertainty on correctness of identification;	I. EDRRCM
	1. Commission standard identification requirements for high-risk species for adoption by agencies
	2. Review identifier accreditation options and propose standards
	3. Consider setting and adopting requirements for laboratory accreditation, including required expertise and technologies
Challenges in working across agencies	I. EDRRCM in partnership with federal agencies
	1. Develop identification protocols at national or regional levels, to promote standardization and regulatory acceptance across agencies

See Table 1 for relevance to a sustainable taxonomic resource for EDRR

identifier authority other than training and workplace monitoring if identifiers are employed in this capacity. For citizen scientists courses are available in invasive species identification. The more tailored they are to sites or species, the better the personnel will be equipped, and the more accurate identifications are likely to be. The eBird citizen science project (eBird 2018a) has implemented a system including automatic data vetting and a network of experts to verify reported data (eBird 2018b). However, since citizen scientists often will be operating in quadrant B of Fig. 2 where the potential for error is highest, protocols to manage identification submissions should be used (Chandler et al. 2017; MacKenzie et al. 2017).

Laboratory standardization and quality assessment

Some federal agencies apply laboratory standards (Food Safety and Inspection Service n.d.; Federal Bureau of Investigation DNA Advisory Board 2010; APHIS 2013). A relevant International Organization for Standardization (ISO) standard was adopted by USDA CPHST Beltsville Laboratory (ISO 2017), which is a key component of the PPQ National Plant Pathogen Laboratory Accreditation Program (NPPLAP; APHIS n.d. a). ISO has developed a biobanking standard, ISO 20387: 2018, which will be modified for various collection types (ISO n.d.). Private contractors may use industry standards and accreditations.

Standardization of identification methods

When an agency develops EDRR protocols, the identification method should be specified (e.g., Federal Interagency Committee for the Management of Noxious and Exotic Weeds 2003; Rabaglia et al. 2008; Trebitz et al. 2017). There is no standard definition of a species, either federally or between taxonomists, and agencies apply different standards to identifications depending on their governing laws and policies. This may limit agencies' ability to make use of identifications from others. The US Federal Bureau of Investigation (FBI) uses the best available published science, but other agencies often rely on their own internal laboratories and procedures. US federal law makes use of the Daubert Standard to assess the validity of expert evidence (Berger 2011); some principles may be transferable. The US Food and Drug Administration (FDA) has also provided DNA barcode standards for their 22 major food-borne pest animals (Jones et al. 2013).

Some standards exist for individual species identifications. Some US agencies use International Plant Protection Convention (IPPC) standards (IPPC 2017; Bostock et al. 2014; APHIS 2017d), but most species are not covered by these. USGS and USFWS laboratories have established sampling method and laboratory proficiency standards for molecular detection of chytrid fungus (*Batrachochytrium salamandrivorans*). The FDA uses the "Regulatory Fish Encyclopedia" (USFDA 2017a), including DNA barcodes and electrophoretic methods, and maintains a Reference Standard Sequence Library for Seafood Identification

(RSSL; USFDA 2017b). The USDA Food Safety and Inspection Service (FSIS) makes available an unendorsed list of test kits that have been validated for detection of pathogens (FSIS 2017) and guidance to evaluate the performance of pathogen test kits (FSIS 2010). There are formal guidelines for DNA Barcode inclusion in BOLD, which include vouchering a specimen (Ratnasingham and Hebert 2007; Hanner 2009). Mickevich (1999) sets out some criteria for identification and quality of names included in databases.

Taxonomic name management

Taxonomic names change as a result of scientific study (Vecchione 2000) at perhaps 1% per year (Smith et al. 2008). A standard list of names is important for information exchange and assessing and managing possible invasive species (Smith et al. 2008; Pyšek et al. 2013; Deriu et al. 2017; Groom et al. 2017), allowing stakeholders to have a single point of reference and remove ambiguity. Data management issues around name providers are addressed by Reaser et al. (2019c, this issue), but there are capacity issues in compiling and maintaining the databases and interpreting and using the contents. Recommendations for taxonomic name management are given in Table 8.

Rapidity of identification needs to be matched by all stakeholders using the same name and species concepts; otherwise there are risks of miscommunication and using incorrect names. No single global source of all scientific names exists, nor does a complete list of US native or invasive species. Without such a list even at the state level, an agency cannot always tell what species are non-native (Great Lakes USFWS team pers. comm).

An authoritative source (name-server) for the currently used names for US federal agencies, the Integrated Taxonomic Information System (ITIS) (Guala 2016), is used by EPA (2000) and USGS and is recommended to its agencies by the Department of the Interior (DOI) (and used by the European Alien Species Information Network [EASIN; Deriu et al. 2017]). It is used by many federal agencies that are signatories to the MoU (https://www.itis.gov/mou.html, accessed 2 October 2018). However, while it is used by some parts of the USDA, it is not used by all (it is not listed in any of the USDA manuals cited in the

references to this paper, for example). Gaps in coverage, including of some agriculturally important insects, may preclude its use by at least some parts of USDA.

There are many catalogues and name-serving databases, although these may differ according to the resources used in compilation, the taxonomists producing them, update frequency, and coverage. They may give different names for the same organism or omit species. Expert taxonomists may not refer to databases but use the most recent scientific literature, often not captured by name-servers. Names supplied by experts may therefore not be easily relatable to names being used by other stakeholders. Different identification technologies may also use different names for the same species.

Hidden risks are associated with *species concepts*. Different names applied over time may not be simply and unequivocally linkable to biological entities. If a species is moved between two genera (e.g., the crazy ant *Paratrechina fulva* Mayr is re-named *Nylanderia fulva* Mayr), the two names refer to the same *species concept* with the same biological properties. When two species are discovered to be the same they are subsequently known by the older name, and again share the same species concept. In both examples users must locate information published under both names, so databases should have both (ITIS n.d.; Guala 2016). However, sometimes what was thought to be a single species is discovered to comprise different entities, e.g., the red palm weevil comprising two species: *Rhynchophorus ferrugineus* (Olivier) and *R. vulneratus* (Panzer) (Rugman-Jones et al. 2013), and biological and other observations recorded under the original name cannot with confidence be applied to one or other of the new concepts. Barcode "provisional nomenclature" to enable reference to informal concepts may be helpful (Schindel and Miller 2009). The issue compounds the problems of unconnected databases. Although there are attempts to manage species concepts in databases (e.g., Franz and Peet 2009), no solutions are accepted widely. Notably, most databases lack a mechanism for alerting users to changes in names or concepts.

Federal agencies use a variety of name providers, some referring to different providers in different documents. There may be static lists either included in the document (e.g., USDA 2012b) or online (e.g., APHIS n.d. a, b), or online databases (e.g., ITIS [http://

Table 8 Taxonomic names: recommendations

Standards—aspects hindering rapid identification and response	Actions
Miscommunication through using different names	I. EDRRCM and name-servers
	1. Raise awareness among stakeholders of potential disparities between databases
	II. Federal agencies
	1. Take steps to harmonize resources used for names
	2. Support major publicly-funded databases, and facilitate closer collaboration between them
Duplication and errors arising from use of different databases	I. Name-servers (databases)
	1. Work together to develop a single portal to names of all organisms, building on existing investments (e.g., ITIS, PLANTS)
	a. Duplication of effort should be avoided
	b. Names should be as up to date and stable as possible
	c. Names should include all US native taxa
	d. Names should include non-native species known to have entered the US and species at risk of entering the US
	e. Synonyms should be included
	f. Unique identifiers for names should be used (e.g., ITIS Taxonomic Serial Number [TSN])
	2. Work with national and international bodies (e.g. Biodiversity Information Standards (TDWG), Catalogue of Life, Global Biodiversity Information Facility) to develop standards for interoperability of databases
	3. Employ such standards to improve coverage and avoid duplication and gaps
Errors through incomplete or outdated databases	I. Federal agencies and funders
	1. Support taxonomists and name-servers to complete and maintain an authoritative database/federated database of names of native and invasive species
	II. Federal agencies
	1. Make use of global databases of invasive species
	III. Name-servers
	1. Agree and implement a universal indication of record quality
	2. Develop systems to alert stakeholders when a name is changed or new invasive species is detected in the US (building on the USGS Nonindigenous Aquatic Species database national alert system)
Concept changes not understood	I. Name-servers
	1. Develop means of showing concept changes

See Table 1 for relevance to a sustainable taxonomic resource for EDRR

www.itis.gov, accessed 1 October 2017]). Some USDA preclearance manuals include lists of plant names that shippers should use, including manual-specific lists derived from the literature or unstated sources, Parasitic Plants Database, Convention on International Trade in Endangered Species (CITES) Species Database, Federal Noxious Weed List, Endangered Species Act (ESA) Listed Plants, and US National Plant Germplasm System (GRIN). In some manuals differences between sources are mentioned.

PoE inspectors are consequently presented with names of consignment contents but, because there is no standard source of names for the shipper (or quarantine staff) to use, some names given in shipping documents may be questionable and not match current identities.

Some name-serving databases are context-specific, although this can be confusing. The Federal Noxious Weed List (APHIS 2010) is a PDF listing 108 species reached from a website "Federal Noxious Weeds"

(Natural Resources Conservation Service 2017) listing 112 species that is derived dynamically from the PLANTS database (Natural Resources Conservation Service 2018). The USDA *Seeds Not for Planting Manual* (USDA 2014b) link named Parasitic Plants Database leads to an undated PDF list of genera with the latest supporting reference dated 2003 (APHIS n.d. b). The US Bureau of Land Management has lists of weeds of concern that "comply with" the Federal Noxious Weed Lists, State Noxious Weeds Lists, and county lists, compiled by a range of stakeholders. The California Department of Food and Agriculture list of weeds (2018b) differs from the USDA California list from the PLANTS database. Inevitably some names on these lists differ even though they refer to the same species. A brief inspection of the US Regulated Plant Pest Table (APHIS 2017e) revealed a number of outdated names. Species listed present (e.g., state lists of invasive species) depend on identification accuracy. Erroneous identifications and unreliable documentation in area lists can lead to large errors (Vecchione 2000).

A global database tailored for Invasive Species, the Global Invasive Species Database (ISSG), is not referred to in any documents reviewed here, even though an early version of this database identified nearly 200 species from a list of imports into the United States between 2000 and 2004 that might pose a national risk (Browne et al. 2007). BISON (USGS 2017), a web-based federal mapping resource for species occurrence data in the United States and its territories (Guala 2017), will tag records as invasive where possible (although this will not indicate invasive status between states in the lower 48). BISON draws on ITIS names plus resources including iNaturalist and collection records.

The resources used across federal bodies to provide scientific names do not all exchange information and are not equally complete or up-to-date, some delivering outdated names or concepts. Some online PDFs are undated and resources may not be removed from the internet when superseded. ITIS and the PLANTS databases have recently agreed to share resources and align their taxonomies. PLANTS is linked to GRIN (ARS 2015). This process needs support, as does continued population of the databases with appropriate quality control. ITIS stipulates high record quality and provides compilation dates, but Mickevich (1999) and Mickevich and Collette (2000) proposed more

extensive criteria to show scrutiny level and verified accuracy for the NOAA/NMFS marine database.

Watch lists (Reaser et al. 2019c, this issue) are developed by federal and state bodies, including by the NPS Exotic Plant Management Teams (EPMT) for National Parks. The Heartland EPMT method was developed by using consensus in the summarized findings of other lists. However, harmonized lists cannot be produced simplistically (Pyšek et al. 2013; Murray et al. 2017).

Names used in legislation or management protocols may not track changes in scientific nomenclature and may refer to outdated concepts, thus not relating to currently recognized problem species. There are procedures for adding names to the Lacey Act list and some of its listed names include alternative scientific names. Some names are listed in legislation at the genus or higher taxonomic level. Thus, when an unexpected diversity was discovered in the snakehead (Conte-Grand et al. 2017), this discovery had no regulatory impact because the Lacey Act lists the entire family (USGS 2004).

Conclusion

Provision of taxonomic support in the United States is under threat. Taxonomists are retiring and leaving the profession, and positions are not being replaced (Stack et al. 2006). Plant pest diagnostic laboratories are affected by decreasing state support, and dependence on fees reduces submission of samples (Stack et al. 2006). Some state universities are disposing of collections and staff and losing the capacity to manage the collections they hold. Fragmentation and isolation of resources and duplication of databases make expertise and information difficult to locate and use with confidence. Action at a local level may be insufficient when the required information or expertise is available only when when one searches at a global scale.

Significant US federal resources are devoted to the IPC for invasive species. Yet, there are also concerning trends and opportunities for improvement. Underlying almost every area is a need to improve collaboration between federal and state agencies and to develop coherent taxonomic support with sufficient expertise rapidly and easily available. If federal and state agencies continue to operate in the current

fragmented and sometimes ad hoc manner, an efficient and effective EDRR process is unlikely, posing a serious risk of invasive species going unmanaged.

Overall, the capacity for rapid and accurate species identification can be improved through the following:

- Establish flexible, yet binding agreements and other coordinating mechanisms among federal agencies, as well as with all others who bear responsibilities for invasive species identification and identification support. The arrangements should detail resource-sharing, delineation of authorities, communications protocols, and sharing and availability of personnel and subject matter experts (Table 2).

- Establish a coordinating body to work with federal agencies and others to facilitate cooperation, information sharing, and standards setting (Table 2).

- Ensure appropriate taxonomic and identification expertise at local, regional, and national levels is available to support EDRR activities, and have those carrying out identifications properly resourced, with staffing and technology, to enable rapid response (Table 3).

- Create a clearinghouse for relevant identification tools, whether online, apps, or paper based, and for sources of identification expertise, and provide recommendations for suitability and quality of identification tools at taxon and regional levels (Table 6).

- Engage with national and international bodies (e.g., Biodiversity Information Standards (TDWG), Catalogue of Life, Global Biodiversity Information Facility) to develop standards for interoperability of databases, employ such standards to improve coverage, avoid duplication and gaps, and enable standardized names to be applied in all cases, including nomenclature, occurrences, legal status, etc. (Table 8).

- Encourage databases serving taxonomic names to collaborate, employ common standards for data exchange and data quality, and develop a portal through which all taxonomic names and their status can be retrieved (Table 8).

- Expand the content of DNA and DNA Barcode libraries to be complete for US native species, and prioritize alien and potential alien species (Table 6).

- Ensure long-term sustainability of biological collections for invasive species activities, including specimens of relevant native and invasive species of confirmed identity (Public Law 111-358 section 104) (Table 5).

- Develop and agree upon standard identification protocols; ensure sufficient diagnostic laboratory capacity and consider developing identifier accreditation systems (Tables 5, 7).

- Engage and empower citizens and citizen science groups to provide identifications of agreed quality using training, technologies, and connections to professional identifiers, and implement quality management systems (Table 4).

The United States does not have a strategy to address the need for rapid identification under EDRR. Such a strategy is needed urgently. Because the United States cannot provide all of the expertise and resources it needs to manage identification of intercepts from other countries, it must have an interest in global capacity. In 2001 the Davis Declaration emphasized the need for international collaboration and strategy to coordinate invasive species taxonomic and information services (Davis Declaration 2001). International networks of taxonomists have been set up, the most extensive being BIONet-International (Jones 1995), although this has been inactive for the past 5 years. Such networks could be revived to support the United States and other countries in identifying invasive species. Networks across the world and within the United States must be resourced to be sustainable and to provide the input required for EDRR. With a critical approach to EDRR and investment in taxonomic capacity, the current risks to effective management can be addressed sustainably.

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