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REVIEW

The early detection of and rapid response (EDRR) to invasive species: a conceptual framework and federal capacities assessment

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Abstract Globalization necessitates that we address the negative externalities of international trade and transport, including biological invasion. The US government defines invasive species to mean, "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." Here we address the role of early detection of and rapid response to invasive species (EDRR) in minimizing the impact of invasive species on US interests. We provide a review of EDRR's usage as a federal policy and planning term, introduce a new conceptual framework for EDRR, and assess US federal capacities for enacting well-coordinated EDRR. Developing a national EDRR program is a worthwhile goal; our assessment nonetheless indicates that the federal government and its partners need to overcome substantial conceptual, institutional, and operational challenges that include establishing clear and consistent terminology use, strategically identifying and communicating agency functions, improving interagency budgeting, facilitating the application of emerging technologies and other resources to support EDRR, and making information relevant to EDRR preparedness and implementation more readily accessible. This paper is the first in a special issue of *Biological Invasions* that includes 12 complementary papers intended to inform the development and implementation of a national EDRR program.

Keywords Detection · Response · EDRR · Invasive species · Federal capacities

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Introduction

The globalization of trade, travel, and transport dictates that we occupy a more interconnected, yet seemingly smaller and increasingly homogeneous world. It also requires that we address the negative externalities of the expanding human enterprise,

including biological invasion. Species that are integral ecosystem components in their native ranges may be labelled "invasive species" and managed when relocated to new ecosystems (Mack et al. 2000; McNeely et al. 2001; Burgiel et al. 2006; Simberloff 2013; Chapman et al. 2017). The US government defines an invasive species to mean, "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." It is US policy to prevent the introduction, establishment, and spread of invasive species, as well as to eradicate and control populations of invasive species that are already established (Executive Office of the President 2016).

Here we address the role of the early detection of and rapid response to invasive species (EDRR) in minimizing the impact of invasive species on US interests. Specifically, we provide a review of EDRR's usage as a term in federal policy and planning, introduce a new conceptual framework for EDRR, assess US federal capacity for enacting EDRR through a coordinated program, and identify needs for improving federal EDRR capacities. This paper is the first in a Special Issue of *Biological Invasions* that includes 12 complementary papers intended to facilitate development and implementation of EDRR capacity nationally. Although the papers in the series have an explicitly federal focus, we recognize that effective and cost-efficient EDRR requires coordination with other countries; state, territorial, tribal, and local governments; non-governmental organizations; the private sector; and the general public.

A comprehensive approach to biosecurity, of which EDRR is a crucial component, is essential for minimizing the negative externalities of globalization (McNeely et al. 2001; Waage and Reaser 2001). Biosecurity is a long-warranted policy agenda in the United States from various national security perspectives, ranging from meeting basic food security needs to protecting the populace from bioterrorism (Meyerson and Reaser 2002a, b, 2003). The transition from a piecemeal approach to addressing invasive species to one that is more coordinated and vigilant will require greater attentiveness to information management, budgets and finances, inspection and quarantine, and eradication and control operations (Reaser and Waugh 2007; Reaser et al. 2008; Waugh 2009). A growing interest in EDRR by federal, state, territorial, and tribal agencies creates the necessary enabling environment for a national EDRR program that facilitates biosecurity across all levels of government.

EDRR in federal definitions, policy, and planning

The term "EDRR" has become topical in invasive species science, policy, and management even though the concept has been largely undefined and inconsistently applied. Table 1 provides an overview of how US government reports and globally-scaled publications, to which the US contributed substantially over the last 25 years, describe or define EDRR. The terms "detection" and "rapid response" are first used in a 2001 report by the US General Accounting Office (GAO), where detection is regarded as the act of surveying for non-native species that have already been introduced and rapid response is any action that enables those organisms to be eradicated or prevented from spreading further.

Although EDRR is frequently mentioned as a key tenet of invasive species management in the publications through 2018, definitions are scant. In general, early detection is considered the process of searching for (surveying) non-native species to prevent the species from becoming established, spreading, and causing harm. However, definitions of early detection also include impact assessment (National Invasive Species Council 2011, 2012, 2013, 2014, 2015, 2016a) or monitoring (US Forest Service 2013). In sharp contrast to other authors, Welch (2014) considers early detection a process for evaluating change in ecological condition and management progress over the long-term. Each of these definitions requires different programmatic goals, designs, and investments, and thus use of the term "early detection" needs to indicate spatio-temporal application.

Rapid response has generally been regarded as an effort to eradicate invasive species, although some federal definitions include containment and/or control measures (National Invasive Species Council 2008, 2011, 2012, 2013, 2014, 2015, 2016a, b; US Department of the Interior 2016). In the term's broadest application, it is not clear how rapid response is to be differentiated from invasive species management as a general concept. Distinguishing what is meant by "rapid" is particularly challenging. We identified a single reference delineating a timeframe

Table 1 Definitions of EDRR and its components

References	Definition	Comments
US Congress, Office of Technology Assessment (1993)	NA	Term not included; focused on invasive species at a national scale
ANSTF (1994)	Not defined	Includes section on detection and monitoring which includes term early detection; focused on aquatic invasive species at a national scale
Executive Office of the President (EO 13112) (1999)	NA	Term not included; focused on invasive species at a national scale
IUCN (2000)	NA	Term not included; focused on invasive species at a global scale
GAO (2001)	*Detection*: surveillance for the existence and location of an invasive species that may have been introduced *Rapid response*: a response conducted in time to eradicate or contain a potentially damaging invasive species	Focused on federal and state funding for invasive species
NISC (2001)	Not defined	Includes section of Action Plan focused on EDRR (pp 34–36); focused on invasive species at a national scale
McNeely et al. (2001)	NA	Term not included; focused on invasive species at a global scale
Wittenberg and Cock (2001)	Not defined	Includes chapter on Early Detection (pp 101–112); focused on invasive species at a global scale
ANSTF (2002)	Not defined	Includes mention of detection and rapid response; focused on aquatic invasive species at a national scale
FICMNEW (2003)	Not defined	Focused on EDRR at a national scale
NISC (2003)	Not defined	Focused on EDRR at a national scale
USFS (2004)	Not defined	Includes section on EDRR; focused on invasive species at a national scale
NISC (2004–2007)	Not defined	Includes section on EDRR; focused on invasive species at a national scale
Westbrooks (2004)	Not defined	Focused on EDRR at a national scale
Lodge et al. (2006)	Not defined	Includes EDRR recommendation; focused on invasive species at a national scale
Simpson (2006)	Not defined	Focused on EDRR at a national scale
ELI and TNC (2007)	Not defined	Focused on EDRR of plant pests and pathogens at a state level
Asian Carp Working Group (ANSTF) (2007)	Not defined 9 related regional plans from 2010–2018 reference EDRR but do not include definitions	Includes strategic elements and action items for EDRR; focused on Asian carp at a regional scale
ANSTF (2007)	Not defined	Includes mention of detection and rapid response; focused on aquatic invasive species at a national scale
Beck et al. (2008)	Not defined	Invasive species definitions in the US policy context
NISC (2008)	*Early detection*: not defined *Rapid response*: a systematic effort to eradicate or contain invasive species while infestations are still localized	Includes section of national invasive species Action Plan focused on EDRR (pp 16–20)

Table 1 continued

References	Definition	Comments
Westbrooks et al. (2008)	Not defined	Focused on EDRR at a national scale
Waugh (2009)	*Early detection and rapid response* (EDRR): a coordinated framework for the management of new invasive species introductions. Elements include detection, identification and vouchering, verification and archiving, rapid assessment, and rapid response	Cites Westbrooks 2004 although not defined in that paper; focused on EDRR at a global scale
USFS (2009)	Not defined	Focused on EDRR at the a national scale
NISC (2012–2017)	*Early detection*: actions taken to detect incipient invasions and assess the current and potential impact of invasions *Rapid response*: a systematic effort to eradicate, contain, or control a potentially invasive non-native species introduced into an ecosystem while the infestation of that ecosystem is still localized, and to eradicate and/or contain invasive species populations while they are still localized	Focused on invasive species at a national scale
Simberloff and Rejmánek (2011)	Not defined	Includes chapter on EDRR (pp 169–176) by Westbrooks and Eplee; largely update of FICMNEW 2003 on invasive species at a national scale
Crall et al. (2012)	Not defined	Focused on EDRR at a regional scale
ANSTF (2012)	Not defined	Includes section on EDRR; focused on aquatic invasive species at a national scale
USFS (2013)	*Detection:* survey to detect new invasive species and monitor existing priority species	
Welch (2014)	*Early detection*: a long-term monitoring process that is "a collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective" Also states managers are to: (1) detect species early (that is, find a new species or an incipient population of an existing species while the infestation is small [less than 1 hectare]) and (2) respond rapidly (that is, implement appropriate management techniques to eliminate the invasive plant and all of its associated regenerative material)	Focused on early detection of invasive plants; cites Elizinga et al. (1998)
US Department of the Navy (2015)	Not defined	Includes EDRR action items focused on EDRR at a regional scale (Micronesia and Hawaii)
US Department of the Interior (DOI) (2016)	*Early detection and rapid response:* a coordinated set of actions to find and eradicate potential invasive species before they spread and cause harm *Early detection*: a process of surveying for, reporting, and verifying the presence of a non-native species before the founding population becomes established or spreads so widely that eradication is no longer feasible *Rapid response*: a process that is employed to eradicate the founding population of a non-native species from a specific location	Focused on EDRR at a national scale

Table 1 continued

References	Definition	Comments
Executive Office of the President (EO 13751) (2016)	NA	Term not included; focused on invasive species at a national scale
NISC (2016b)	Same as DOI 2016	Focused on invasive species at a national scale
CAFF and PAME (2017)	Same as DOI 2016	Focused on invasive species at a regional scale (Arctic)

for eradication: Lodge et al. (2006) indicates that eradication efforts must proceed within weeks or, at most, 1–2 years for a rapid response to be successful. Because invasion scenarios are unique, the timeframe to achieve eradication is context-specific.

Two publications explicitly combine early detection and rapid response as a single, defined concept. Waugh (2009) refers to EDRR as a coordinated framework for the management of new invasive species introductions, while the US Department of the Interior (DOI 2016) regards EDRR as a coordinated set of actions to find and eradicate potential invasive species before they spread and cause harm. Both definitions emphasize (1) a need for coordination (among government agencies and a wide range of non-governmental stakeholders) and (2) a focus on taking action at the introductory stage of the invasion process.

Although the Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW 2003) and Westbrooks (2004) do not define EDRR, they provide a series of statements about EDRR that contrast with other presentations of the concept (Table 2). These authors, and perhaps the weed science community more generally, may view EDRR in a manner that differs from those focused on other taxonomic groups. This ambiguity further underscores the need for a clear, consistent use of terminology to avoid confusion regarding goals and procedures.

Further confusion over the meaning of EDRR arises relative to the concept of prevention. Authors typically argue that prevention—the action of stopping invasive species from being introduced or spreading into a new ecosystem (Executive Office of the President 2016)—is the most cost-effective strategy for addressing potentially invasive species before they can cause harm (McNeely et al. 2001; Leung et al. 2002; US Forest Service 2004; Lodge et al. 2016). However, prevention measures at points of entry (jurisdictional or ecological) and along invasion pathways (the mechanisms and processes by which non-native species are moved, intentionally or unintentionally, into a new ecosystem [Executive Office of the President 2016]) are insufficient to intercept all invasive organisms (Meyerson and Reaser 2003; Reaser and Waugh 2007). Authors thus frequently state that when prevention fails, the next imperative is to detect and manage (eradicate or control) the invasive organisms as quickly as possible, maximizing cost-effectiveness while minimizing non-target impacts (National Invasive Species Council 2003; Simpson 2006; Environmental Law Institute and The Nature Conservancy 2007). In accordance with these assessments, EDRR is thus considered the second line of defense (FICMNEW 2003; National Invasive Species Council 2003, 2008, 2016b; Westbrooks 2004; Waugh 2009).

The United States defines the term "introduction" to mean, "as a result of human activity, the intentional or unintentional escape, release, dissemination, or placement of an organism into an ecosystem to which it is not native" (Executive Office of the President 2016). In order to prevent an invasive species from being introduced into a new ecosystem, it must be detected and removed from the ecosystem as quickly as possible. From this perspective, early detection and rapid response could thus be regarded as approaches for enacting the goal of prevention (preventing jurisdictional entry or spread among ecosystems), rather than as a separate, secondary concept, framework, or method.

Despite lack of a clear, operational definition of EDRR or its components, federal agencies have been investing in EDRR. Recognizing that budgetary policy can unite agencies in a common purpose or pit them against each other, Reaser and Waugh (2007) recommended that the National Invasive Species Council

Table 2 A comparison of EDRR frameworks

References	FICMNEW (2003), Westbrooks (2004)	NISC (2003)	Westbrooks et al. (2008)	Waugh (2009)	USFS (2009)	DOI (2016)
Component I	Early detection and reporting	Early detection	Early detection and reporting	Detection	Identify potential threats	Preparedness
Component II	Identification and vouchering	Rapid assessment	Identification and vouchering	Reporting	Detect actual threats	Early detection
Component III	Record verification	Rapid response	Record archiving	Record verification	Assess impacts	Rapid assessment
Component IV	Record archiving		Rapid assessment	Identify/initiate response options	Respond	Rapid response
Component V	Rapid assessment		Rapid response	Further evaluation and response		
Component VI	Rapid response					

(NISC) undertake an annual, government-wide budget analysis to elucidate broad trends in federal funding for invasive species activities over time, encourage federal agency cooperation for shared responsibilities, and facilitate cost-effectiveness. NISC began coarsely quantifying EDRR spending in 2004 but did not implement the recommended standardized approach to interagency budget reporting until 2011. Table 3 summarizes EDRR expenditures for those NISC agencies that provided accounting information during the 2011–2016 time period. The variation in relative scale of spending reflects the perceived relevance of EDRR to agency missions, with agencies having agriculture (including livestock), natural resource, and/or land management obligations devoting the most funding to EDRR. Due to variations in agency accounting and the inherent challenges in tracking relevant funds not explicitly appropriated under the designation "invasive species," these numbers should be considered a conservative estimate of EDRR expenditures.

The overall scale of EDRR funding as a percentage of total invasive species spending by the reporting federal agencies is less than 50%. With the exception of what the Department of Homeland Security reports as prevention, review of the comprehensive budget analyses (NISC 2011, 2012, 2013, 2014, 2015, 2016a) reveals that more federal agency resources are being devoted to the control of already established invasive species instead of reducing the risk of future invasion. These financial allocations are inconsistent with White House directives (Executive Office of the President 1999, 2016) for cost-efficiency.

Although the effectiveness of federal EDRR programs has not been comprehensively assessed, authors have regarded effective EDRR as rare (Simberloff 2003a) and pointed to informational, managerial, and financial constraints as barriers to success (GAO 2001; Crall et al. 2012). In recent years, several high-profile invasive species were detected early in the invasion process, but the lack of a well-coordinated, rapid response effort prevented eradication (DOI 2016). However, case studies of effective EDRR-relevant initiatives involving federal agencies and their partners are increasing and have appeared in federal reports (US Forest Service 2009, 2013; DOI 2016; Wallace et al. 2018) and elsewhere (Simberloff 2003a; Waugh 2009). Submissions for the federal EDRR capacity assessment (discussed later; Supplementary information) informed the NISC Secretariat's recently published narratives on federal successes in invasive species prevention and management (Holland et al. 2018). Here, in order to build on existing case studies and develop a more comprehensive approach, we provide an integrated and iterative conceptual EDRR framework, an assessment of federal capacity, and a summary of key findings.

Table 3 Federal EDRR interagency budget 2011–2016 (in millions)

	2011	2012	2013	2014	2015	2016
Total spending[a]	$2239	$2205	$2146	$2204	$2298	$2287
Department of Homeland Security	646.3	665.4	647.6	704.6	745.0	782.5
Department of Commerce (National Oceanic and Atmospheric Administration)	0.75	0.25	0.09	0.07	0.19	0.03
Department of Defense (United States Army Corps of Engineers)	9.02	7.86	8.40	9.20	14.07	15.30
Department of the Interior	8.12	7.54	8.17	13.51	15.70	16.80
Department of State	0.00	2.83	2.77	2.56	0.73	0.80
US Agency for International Development	1.09	No data	No data	No data	1.01	1.13
US Department of Agriculture	242.58	262.46	262.11	264.97	277.35	287.31
Total EDRR spending	907.86	946.34	929.14	994.91	1054.05	1103.87
% of Total federal invasive species spending	41	43	43	45	46	48

[a]Total spending on invasive species by Department/Agency. Department of Transportation (DOT) and National Aeronautics and Space Administration (NASA) provided crosscut figures, but did not report spending on Early Detection and Rapid Response (EDRR). Department of Homeland Security (DHS) classifies all of its spending under Prevention. It is classified as EDRR for the purposes of this table since much of this activity is focused on interception at ports of entry. Environmental Protection Agency (EPA) is responsible for administering funding under the Great Lakes Restoration Initiative (GLRI), which includes work on EDRR by a number of federal and state agencies. However, Environmental Protection Agency does not provide detailed accounting for GLRI across the National Invasive Species Council (NISC) crosscut categories

A conceptual EDRR framework

We define early detection and rapid response (EDRR) 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 have been assessed (i.e., risk and feasibility screening completed; discussed below).

Although frameworks differ in the manner in which EDRR components are combined or split, there is general agreement regarding (1) the necessary components of the process and (2) that operational frameworks function most effectively with integrated communication chains between authoritative decision-makers and field-based implementers (DOI 2016). In practice, EDRR is a non-linear, iterative, self-referential process. Therefore, we portray EDRR as the tenet for an integrated system (Fig. 1) rather than a step-wise set of components addressed in a linear manner, as has been typical of other EDRR frameworks (Table 2). We discuss all of the Fig. 1 components below, as well as in complementary papers in this Special Issue. Note that our framework places emphasis on target analysis and feasibility screening, two components not explicitly identified in other models.

Target analysis

The effort and costs required to detect a species are inversely proportional to its population size (Lodge et al. 2006). However, it is necessary to conduct intensive surveys for organisms that occur at low densities in order to keep the populations from expanding (Simberloff 2003a) and/or assess the scale of the problem from the outset. Target analysis is an examination of the potential for detecting an invasive species at a specific locality and time, using a particular approach and/or technologies. It is employed to maximize the effectiveness and cost-efficiency of invasive species detection when the target species is known, mobile, self-perpetuating, and rare (Morisette et al. 2019, this issue). Invasive species surveillance is particularly important near high risk areas, including airports, shipping/transfer ports, distribution warehouses (GAO 2001; Lodge et al. 2006), and potential recipient ecosystems that have previously been invaded or otherwise disturbed (Morisette et al. 2019, this issue). Sampling

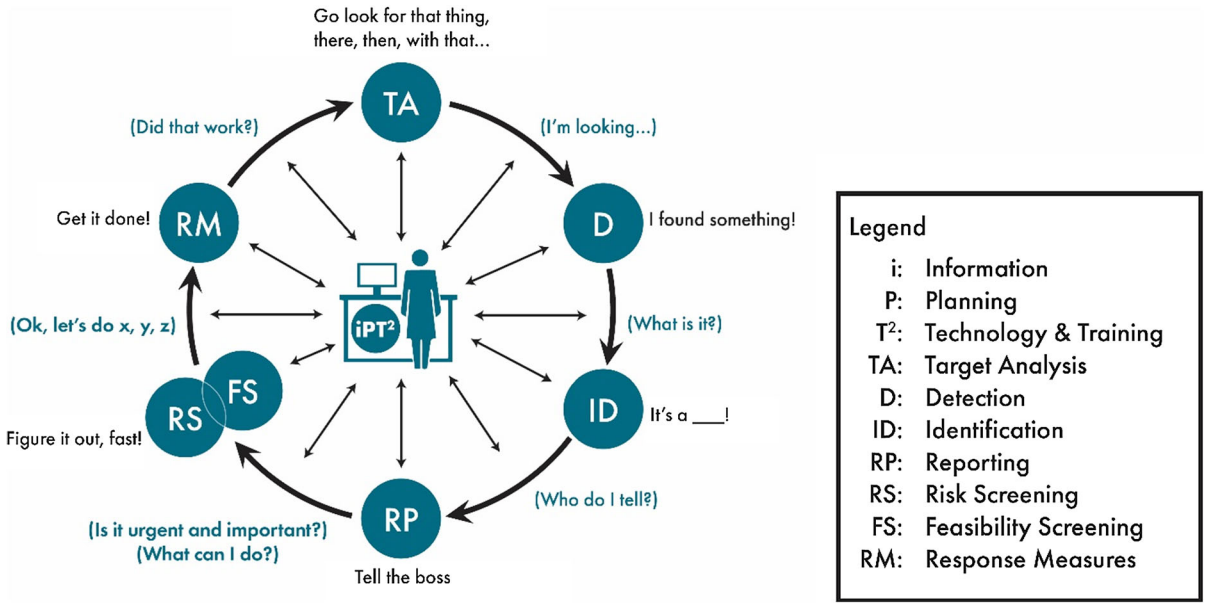

Fig. 1 EDRR: a comprehensive system. In this model, the blue circles represent the primary actions (components) that need to be enacted in a step-wise manner for the effective detection of and response to a biological invasion. A legend clarifies the meaning of the letters in the circles. The associated commentary reflects the primary questions, observations, and directives that guide the process from one component to the next. At the core of the process, represented by the person and work station, are the informational and technical inputs necessary for the system to function. Arrows point in both directions in an effective system because the information and other outputs generated by one component are strategically utilized by other components. As is true of all models, this is a simplistic depiction of reality; implementation of EDRR is a complex, iterative process that requires context-specific adaptation

techniques that maximize search area per unit cost and minimize laboratory (or other analytical) costs are likely to return the best cost–benefit ratios (Hayes et al. 2005).

Detection

We define "detection" as the process of observing and documenting an invasive species. The observation may be made via a survey undertaken with the specific intent of locating invasive species (targeted detection) or during other routine activity (incidental detection), including biological surveys undertaken for other purposes (Welch 2014). Detection is commonly cited as a best management practice for the eradication or control of species that are newly introduced to an ecosystem (Wittenberg and Cock 2001; Westbrooks 2004; Crall et al. 2012), although detections can also be of established species in areas not previously surveyed or organisms overlooked during previous surveys (Welch 2014). US Department of Agriculture (USDA) officials suspect that the Asian long-horned beetle (*Anoplophora glabripennis*) was in the United States for up to 10 years before it was reported in New York in 1996. *Caulerpa taxifolia*—a highly invasive seaweed—was likely introduced 4 years prior to being reported in California in 2000 (GAO 2001). Historically, detection has been considered an explicitly site-based activity that relies heavily on visual encounter surveys. However, advances in technologies are enabling remote detection of invasive species (Martinez et al. 2019, this issue). The purpose of documenting the organism is to (1) collect sufficient information to record locality (ideally, point location using GPS coordinates) in a manner that facilitates response measures and (2) provide sufficient information (ideally, a voucher specimen) to obtain an authoritative identification of the organism(s) (see next section). Until the identification has been authoritatively established, detection of an invasive species should be considered tentative and response measures handled accordingly.

Identification

We define "identification" as the provision by an expert of a taxonomic identity to an organism to a degree that avoids/minimizes confusion between taxa with different biological properties and that allows access to information about (1) the taxon to which it belongs, (2) risk analysis and (3) if appropriate, management measures to be put in place. Identifications may be made based on morphological and/or genetic traits. Although an increasing number of informatics tools are available to assist with identification (Martinez et al. 2019, this issue), identification as used for the purposes of this paper implies identification by a taxonomic authority whose findings can be considered conclusive and warrant the investment of further authoritative actions (Lyal and Miller 2019, this issue).

Reporting

We define "reporting" as providing an account of an invasive species (detection and identification information) to the authority ("The Boss"; Fig. 1) responsible for assessing the necessity, capacity, and/or form of response measures. The most appropriate authority (individually and institutionally) to which to report may vary depending on the species identified and its location, relevant legal and policy frameworks, and each authority's available resources. Under some circumstances (e.g., when an emergency response plan is in place), reporting may involve a single action from one authority (taxonomic identifier) to another (natural resources director). However, it is more likely that the reporting process will involve multiple players and multiple channels of communication.

Reporting might also involve disseminating alerts to increase survey vigilance and the additional reporting of detections, especially when the species has previously not been intercepted or considered high risk or both. Ideally, these alerts are made publicly available to encourage engagement of non-governmental and citizen scientists (Lodge et al. 2006). Ultimately, reporting outputs should also include entry of information into publicly available databases (Reaser et al. 2019a, this issue) and the peer-reviewed literature, such as presented by McCullough et al. (2006).

Risk screening

We define "risk screening" as a rapid characterization of the types and degree of risks posed by a population of non-native species in a particular spatio-temporal context. Risk screening is employed to efficiently ascertain if the identified impacts are (a) "low," as to warrant no response measures other than making these findings publicly available; (b) "high," as to warrant immediate, priority action as feasible, including consistency with regulatory frameworks that might require a more detailed risk analysis as a next step (Burgos-Rodríguez and Burgiel 2019a, this issue); or (c) "uncertain" due to a paucity of reliable information, as to warrant more extensive data collection and analysis before response measures are considered. In the context of EDRR, it is essential that risk screening approaches are designed to facilitate processing speed and outcome accuracy. Meyers et al. (2019, this issue) explicitly address risk screening in the context of federal EDRR capacities.

Feasibility screening

The likelihood that response measures will be effective depends largely upon the species in question and the context in which it is detected; both have implications for the logistical feasibility of a response (Simberloff 2003a; Waugh 2009). We define "feasibility screening" as a rapid assessment (ideally, hours to days) employed to measure the ability and likelihood of successfully completing response measures (defined below), taking all relevant factors into consideration (including financial, technological, legal, and scheduling variables). Ideally, each feasibility screen results in a publicly accessible feasibility report that is delivered to the authority for directing response measures (which may be multiple entities). If insufficient information is available to conduct a feasibility screen, a more extensive evaluation (including additional data collection) may be warranted. However, because invasive species are mobile and self-perpetuating, additional feasibility conflicts may emerge between the time required to ascertain information (for any EDRR component) and the ability to eradicate or contain the organisms of concern.

Response

We define "response" as the process of reacting to the detection once the organism has been authoritatively identified and response options adequately assessed. Response measures may fall into four general (non-exclusive) categories: (1) documentation, (2) further analysis, (3) eradication, and (4) control (containment). "No response" should not be regarded as an acceptable response option; at a minimum, information obtained during the target analysis (if there was one), detection, identification, risk screening, and feasibility screening should be made publicly available for future reference (i.e., documentation only). If the risk and/or feasibility screening did not provide sufficient information on which to base a management action, then further analysis may be warranted (Meyers et al. 2019, this issue).

The federal government defines "eradication" as "the removal or destruction of an entire population of invasive species" and "control" as "containing, suppressing, or reducing populations of invasive species" (Executive Office of the President 2016). Public perception plays a substantial role in determining which species, pathways, and ecosystems warrant management. Eradication and control measures are generally focused on species perceived as high risk and assets perceived to be of high value (Reaser and Waugh 2007; Waugh 2009). Eradication is the ideal management response because it provides for a one-off investment in resource protection. Eradication should not be regarded as a cheap, one-step action, however. Eradication efforts may require substantial financial resources, be socio-politically challenging, and take years to accomplish. See Simberloff (2003a) for a review of eradication measures in the invasive species context and Martinez et al. (2019, this issue) for information on advances in eradication technologies.

When eradication is not possible, it may be necessary and feasible to control the most threatening populations to protect key assets and/or prevent populations from proliferating to the point that they overwhelm or forestall any future management measures. Invasive species control measures are largely reported for individual projects, but only a few comprehensive reviews of control methods are available (e.g., Wittenburg and Cock 2001; Hussner et al. 2017). We emphasize the need for response measures to be tailored to specific contexts in order to be effective. We encourage practitioners to regard control not as an end goal, but as a strategy to minimize the spread and impact of invasive species while new approaches are developed that could enable future eradication (especially advanced technologies; Martinez et al. 2019, this issue).

EDRR does not end with the enactment of eradication and/or control measures. The adequacy of these actions needs to be assessed and surveys conducted through time (i.e., monitoring) to protect valued assets from future invasions of the same or other non-native species of concern. Ideally, target analyses are undertaken to ensure the effectiveness and cost-efficiency of these follow-up actions. If new detections occur, then the process begins anew. Thus, from some vantage points, most eradication and control can be considered prevention strategies; we protect recipient ecosystems by increasing their resistance and resilience to biological invasion and ameliorate the environmental and socio-cultural conditions that facilitated the introduction and spread of invasive organisms into specific ecosystems.

The EDRR system described above is enabled by several core components: information systems, planning, technology, and training (Fig. 1). All aspects of EDRR require these core components for effective operation, albeit to varying degrees and in different forms.

Information

NISC (2008) states that EDRR depends upon the timely ability to answer critical questions, such as, (a) What is the species of concern, and has it been authoritatively identified? (b) Where is it located and likely to spread? (c) What harm may the species cause? (d) What actions (if any) should be taken? (e) Who has the needed authority and resources to respond? and (f) How will the efforts be funded?

Thus, EDRR effectiveness depends on the availability of accurate, up-to-date information at every stage in the process (Fig. 1; Reaser et al. 2019a, this issue). The lack of adequate scientific and technical information relevant to the invasive species in question may be one of the most substantial barriers to enacting EDRR (Reaser et al. 2019a, this issue). Although nearly all EDRR components require information on the current distribution and abundance of

non-native organisms (Crall et al. 2012; Lodge et al. 2016), there has been relatively little attention to or investment in collecting and reporting non-native species until recently (Reaser et al. 2019a, this issue). Also, numerous organisms have yet to be identified at the species or sub-species level, and we lack the knowledge of basic biology for a large percentage of those species for which we do have a taxonomic name (Lyal and Miller 2019, this issue). Absent this information, we may not be able to undertake target analyses and risk screening or determine best practices for eradication or control measures. Sustained investment in collecting, reporting, and species identification is thus a fundamental need for effective EDRR.

Although biological information is a vital component of the EDRR process, we want to emphasize that a lack of species-specific data does not justify inaction. Certainty is far more concept than reality in natural systems. In order for responses to be rapid and thus effective, eradication and containment measures need to be enacted based on the information available at the time of detection. As more data become available, response measures can be modified in line with adaptive management principles. For further discussion on the implications of "imperfect" data for EDRR, see Simberloff (2003b).

Planning

Systematic planning and preparedness are essential to ensure agencies are ready to address invasive species incursions (US Forest Service 2009). Advance, detailed (yet flexible) planning is fundamental to all the aforementioned EDRR components. At the institutional level, planning must not only include the establishment and enforcement of the laws and policies that direct and facilitate EDRR (Burgos-Rodríguez and Burgiel 2019a, this issue), but also clearly establish roles, responsibilities, and accountability. A GAO (2001) study revealed that disagreements over who had the authority to assume various leadership roles (including funding commitments) has hampered response capacities, efficiency, and effectiveness in the past. Waugh (2009) points out that the challenges and impacts posed by invasive species are consistent with the federal government's National Response Framework (see US Department of Homeland Security 2016 for the most recent version) and thus should be addressed consistent with emergency response planning (see also Burgiel 2019, this issue).

Depending on the agency involved and the complexity of the EDRR target, planning may be streamlined or tiered with supporting components. For example, the Asian Carp Regional Coordinating Committee—comprised of federal, state, municipality, and Canadian agencies—has an overall national plan, which is further detailed in regularly updated plans focused on more specific aspects (e.g., action plans, monitoring and response plans, contingency plans). Such plans clarify the suite of ongoing actions (e.g., surveys and monitoring), as well as the process and criteria that trigger a response. At the ground level, this could culminate in implementing on-site Incident Command System (ICS) responses that guide further actions (Burgiel 2019, this issue).

Planning should also include scientific and technical analyses that enable greater EDRR preparedness and the establishment of clear program priorities. For example, horizon scanning, which we define as the systematic analysis and reporting of information about future threats or opportunities to inform decision making at specific time intervals, is used increasingly as a tool for addressing biological invasion (US Environmental Protection Agency 2008; Roy et al. 2014; Ricciardi et al. 2017).

Technology

We define "technology" as the outputs of mental and physical effort, including tools and machines, intended to serve a societal value. In EDRR, technology applications range from basic computing to genetic tools (e.g., gene editing, eDNA) for species detection or population eradication and/or control. Recent reviews particularly relevant to invasive species EDRR include an assessment of current methods for tracking the spread and impact of invasive species (Kamenova et al. 2017), a summary of advanced genetic technologies for invasive species detection and management (Invasive Species Advisory Committee 2017), and an extensive overview of emerging technologies for addressing invasive species (Martinez et al. 2019, this issue).

Training

We take a broad perspective on training, regarding it as the act of building the capacity of individuals and/or institutions to effectively implement a particular (ideally, standardized) action, skill, procedure, or protocol. Some aspects of EDRR require more highly skilled and consistently repeated actions than others. For example, shooting invasive goats from a helicopter necessitates extensive experience by the pilot and the hunter, including the flexibility to alter methods as terrain and population size dictate. Approaches to target analysis, risk screening, and feasibility screening should ideally be standardized to enable comparability and consistency in policy application and may benefit from some degree of automation if the requisite databases and associated analytical tools were developed.

Federal capacities assessment

The *2016–2018 NISC Management Plan* includes several action items intended to advance EDRR (NISC 2016a). These action items involve recommendations set out by DOI (2016) in response to the White House's Council on Climate Preparedness and Resilience priority agenda (Climate and Natural Resources Working Group 2014).

In order to implement the NISC management plan directive, the NISC Secretariat invited the twelve Executive Branch Departments and Agencies represented by Council leadership as of August 2016 (https://www.doi.gov/invasivespecies/about-nisc) to respond to a survey (Supplementary information). Table 4 provides a summary of agency responses by survey topic. Gathering information via federal survey is notoriously challenging due to variations in how agencies communicate information (requests/responses might not reach key personnel), competing priorities and frequently heavy staff workloads, and concerns that information will be misinterpreted or used to the agency's detriment (e.g., for future budget cuts). In the case of the EDRR survey, three data limitations need to be considered: (1) not all agencies responded (some do not have missions relevant to EDRR), (2) the depth of responses varied widely among agencies, and (3) agencies may have initiatives relevant to EDRR but not identified as such by the agency because the program was developed with different goals in mind. Whenever possible, the authors of the EDDR assessments featured in this Special Issue thus augmented the federal survey information with agency staff interviews, reviews of information available through federal websites and reports, peer-reviewed literature, and their own programmatic expertise. The findings reported in this paper arise from this comprehensive approach to information gathering.

Noteworthy gaps in the federal capacity assessment remained despite best efforts to gather sufficient data. The EDRR programs and federal institutional frameworks currently being used by the federal agencies to implement EDRR were not evaluated for duplication, potential improvement, or effectiveness. Insufficient time and staffing prevented us from being able to assess the types of response measures used by the agencies and their effectiveness across context and taxa, or to determine the applicability of federal and federally-funded biodiversity inventory and monitoring programs to EDRR. Finally, the agencies were challenged in their ability to provide information on and examples of decision support tools used as part of an EDRR framework. While gaps occur in agency responses, the information provided enables a coarse-scale evaluation of agency perspectives on EDRR, insight into existing programs and their operational mechanisms, shared challenges and needs, and reports of species and locality-specific successes (case studies).

The papers in this Special Issue focus on various aspects of the federal capacity assessment: incident response (Burgiel 2019, this issue), information management (Wallace et al. 2019, this issue; Reaser et al. 2019a, this issue), law and policy (Burgos-Rodríguez and Burgiel 2019a, b, this issue), risk screening (Meyers et al. 2019, this issue), systematics and taxonomy (Lyal and Miller 2019, this issue), target analysis (Morisette et al. 2019, this issue), tools and technology advancement (Martinez et al. 2019, this issue), and watch lists (Reaser et al. 2019b, this issue). The collective findings and recommendations are synthesized in an EDRR blueprint (Reaser 2019, this issue). Here we summarize the cross-cutting assessment findings that have substantial implications for high-level policy and planning, as is consistent with NISC's mission:

Table 4 Federal EDRR survey response

	Federal EDRR programs	Legal authorities	Assessing risks	Inventory and monitoring programs	Identification and reporting	Information systems	Tools and technology
Department of State	X	X	X	–	–	–	–
Department of the Treasury	–	–	–	–	–	–	–
Department of Defense	X	X	X	X	X	X	–
Department of the Interior[a]	X	X	X	X	X	X	X
Department of Agriculture[b]	X	X	–	–	X	X	X
Department of Commerce	–	–	–	–	–	–	–
Department of Health and Human Services	–	–	X	X	X	X	–
Department of Transportation	X	X	–	–	–	–	X
Department of Homeland Security	–	–	–	–	X	–	–
National Aeronautics and Space Administration	X	–	X	–	–	–	–
Environmental Protection Agency	–	–	–	–	–	–	X
US Agency for International Development	–	–	–	–	–	–	–
Office of the United States Trade Representative	–	–	–	–	–	–	–

[a]Responses from the DOI were provided by the Bureau of Indian Affairs, Bureau of Land Management, National Park Service, US Fish and Wildlife Service, and US Geological Survey

[b]Responses from the USDA were provided by National Institute of Food and Agriculture and Agricultural Research Service

Terminology

The GAO (2001) noted a need to clarify what constitutes EDRR before there can be any progress in relevant legislation and funding levels. Our assessment indicates continued inconsistency in definition and application of EDRR-related terminology among and within federal agencies, resulting in miscommunication, resource inefficiencies, and operational ineffectiveness. Of particular note is a failure of federal agencies to standardize their use of the terms "non-native" and "invasive species," despite the federal definitions having been established in Executive Order 13112 in 1999 (Executive Office of the President 1999).

In this context, terminology is not an issue of semantics; terminology has a strong influence on decision-making. Words are the hooks on which policies and regulations are hung. They determine prioritization and resource allocation, and they can frame biological and socio-economic analyses. Without transparent application and agreement on terminology, we will be unable to develop a clear, consistent, and comprehensive understanding of EDRR objectives, strategies, and operational procedures. It will thus be impossible to develop a coordinated, national EDRR framework or initiatives in which participants can contribute to a common vision and effectively enact their roles and responsibilities.

Federal leadership niche

The federal government does not have the authority or capacity to unilaterally operate a national EDRR program. It does, however, have specific responsibilities that need to be met (Executive Office of the President 1999, 2016) to minimize the burden on other sectors. Collectively, federal leadership roles include (a) detection and interception at points of national entry and, in some cases, along inter-state transport pathways; (b) conducting EDRR in federally owned and managed lands and waters, as well as in other circumstances where federal funding is being applied; (c) programmatic guidance and support for the core EDRR inputs (Fig. 1) to strengthen the capacity of all individuals and institutions; and (d) providing grants or other forms of assistance to increase operational capacity, especially to states, territories, and tribes.

Federal engagement

Federal agency engagement in EDRR reflects the extent to which agencies regard addressing invasive species as central to their mission and are willing to prioritize support for EDRR in an atmosphere of resource scarcity. The survey responses suggest that some agencies are not fully aware of the assets they have to contribute to a national EDRR program; in several instances authors of the papers in the Special Issue were aware of relevant programs not identified by the agency respondents. Historically, federal investments in EDRR have been largely oriented towards the protection of crops and livestock (GAO 2001). However, our assessment reveals that all federal land management agencies are, to some degree, enacting EDRR. This includes agencies that do not have agriculture or natural resource protection as a primary mission area (e.g., Department of Defense, National Aeronautics and Space Administration). The data and other resources necessary to support EDRR are frequently provided by agencies other than those leading on-the-ground EDRR efforts. Fundamentally, our findings indicate that there is a co-dependency among agencies for enacting effective EDRR and, thus, a whole-of-government approach to a national EDRR framework is warranted.

Operational structure

To date, EDRR efforts (federal and otherwise) have been largely reactive, facilitated on an ad hoc basis, species-specific, and locally coordinated. Memoranda of agreement or understanding among agencies and with non-federal partners are used to institutionalize EDRR planning and operational measures in specific contexts. However, many agencies lack the ethos, legal authority, and managerial directives necessary for EDRR preparedness, including ongoing investment in the core inputs (Fig. 1), undertaking of relevant analyses (e.g., horizon scanning), development of authoritative response plans (e.g., ICS), and establishment of rapid response funding mechanisms.

Species identification

The GAO (2001) reported inadequacies in detection capacity for microscopic, aquatic, and cryptogenic organisms. Our assessment indicates that EDRR initiatives continue to be strongly biased, largely toward invasive insects and pathogens that impact crops ("quarantine pests") and invasive plants in general. However, it also reveals that substantial progress has been made in addressing aquatic invasive species (e.g., Fuller and Neilson 2015). The National Park Service also recently recognized the need for increased efforts to address invasive terrestrial animals (Redford et al. 2017; Resnik 2018).

Information access and sharing

Because every EDRR component relies on readily available, accurate, up-to-date information, the strength of any EDRR initiative is determined by the ease of information access. As standard practice, federal agencies do not internally share (within or across agencies) or make publicly available much of the information needed to support a national EDRR program (Fig. 1). Exceptions may include laws and policies (Burgos-Rodríguez and Burgiel 2019a, this issue), as well as some non-native species occurrence data (Reaser et al. 2019a, this issue), alerts, and watch lists (largely agricultural or forestry-related; Reaser et al. 2019b, this issue).

The response toolkit

Because no two invasion scenarios are identical, a large, diverse, flexible toolkit is needed to achieve invasive species detection, eradication, and control. To date, this toolkit has proven too limiting for many species managed by federal agencies; the government and its partners are spending millions of dollars annually to manage single, high-impact species, such as Asian carp (e.g., silver carp, *Hypophthalmichthys molitrix*), brown tree snakes (*Boiga irregularis*), zebra mussels (*Dreissena polymorpha*), and Asian long-horned beetles (*Anoplophora glabripennis* (Martinez et al. 2019, this issue). However, an increasing number of examples demonstrate that federal investments in technology are paying off, literally and figuratively (Conservation X Labs 2017a, b; Holland et al. 2018; Martinez et al. 2019, this issue). Waugh (2009) noted that the United States could become a world leader in detection and response capacity if the invasive species issue was given priority in government policy commensurate with the risk that it poses to the national economy and biological resources. This perspective is consistent with the emphasis on technology advancement found in Executive Order 13751 (Executive Office of the President 2016).

Programmatic investments

If the federal capacity assessment focused purely on initiatives explicitly designed to support invasive species EDRR, or some component of it, we would conclude that the federal government lacks adequate resources. Although agencies can certainly justify their calls for additional resources (discussed below), there are also substantial opportunities to capitalize on existing programs in which the federal government has already invested hundreds of millions of dollars over decades. These include biodiversity surveillance and monitoring programs, information systems, research and development programs, and environmental education and outreach initiatives that have historically focused on native species. In many cases, small investments in programmatic "retrofitting" could substantially increase our ability to detect and respond to invasive species. Opportunities also exist in the agriculture and human health sectors to clarify that many of the programs focused on pests or disease are, by definition, invasive species programs and warrant greater linkages with invasive species-related initiatives in the environmental sector. The One Health approach could be an asset in this regard (http://www.onehealthinitiative.com, accessed 13 September 2019).

The case for federal financial investments in EDRR is typically made based on the understanding that failure to rapidly detect and respond to invasive species results in far greater expenditures by agencies and a wide range of stakeholders than would otherwise be necessitated (GAO 2001; DOI 2016). Consistent with the GAO's (2001) and DOI's (2016) findings, agencies routinely report insufficient funding for EDRR preparedness and enactment, particularly rapid response measures. The annual NISC interagency budget analysis was terminated in 2017, making it even less likely that a multi-agency approach to better resourcing of EDRR could be developed in a well-informed, strategic, and justifiable manner. Waugh (2009) cautions that it is not realistic to rely on Congressional appropriations for funding and points to programs (e.g., boll weevil management) in which responsibility is shared between the federal government, industry, and other stakeholders who otherwise would be incurring the costs of impacts.

Effective EDRR

Where agencies have successfully implemented EDRR, or at least some aspects of it, those initiatives have been characterized by (a) adequate information provided to authoritative decision makers in a standardized and timely manner; (b) effective coordination (often pre-established through agreements) among neighboring land owners/jurisdictions; (c) enactment of detection and response measures prior to species establishment in a new range; (d) institutionally, logistically, and socially well-supported response measures; (e) response measures that include actions taken to prevent the re-invasion or spread from invaded sites or both; (f) incorporation of lessons learned from previous EDRR experiences, both successful and non-successful; and (g) investments made in preparation to address future invasion. These findings are largely consistent with those reported elsewhere (e.g., GAO 2001; NISC 2003; Waugh 2009; DOI 2016).

Key findings and conclusion

EDRR should be considered a first principle of effective and cost-efficient strategies to address invasive species. While developing a national EDRR program is a worthwhile goal, the federal government and its partners will need to overcome a substantial number of conceptual, institutional, and operational challenges if success is to be achieved. Addressing these challenges will require a federal initiative that focuses on foundational needs and progresses in an iterative manner to construct a logical framework that is well integrated across agencies, from senior decision making to field implementation levels. The following is a list of the cross-cutting foundational needs revealed through the federal capacities assessments:

1. *Legal structure and institutional framework* In accordance with Executive Orders 13112 and 13751, as well as other complementary executive guidance, delineate and communicate a national legal and institutional framework for enabling EDRR across taxa and geographies.
2. *Terminology* Clear definitions of relevant terms need to be standardized as feasible, institutionalized, and well-communicated. Ideally, this would be accomplished through an executive order and/or legislation.
3. *Operational plan* Once terms have been clarified, a strategic communications initiative needs to be implemented to demonstrate the relevance of invasive species EDRR to agency missions. The ideal output would be a regularly updated, online plan or related directory that provides information on agency roles and responsibilities relevant to the EDRR components listed in Fig. 1, including contact information for authoritative focal points.
4. *Asset inventory* A clear understanding of how invasive species relate to an agency's mission is necessary to enable agencies to identify their most important assets for supporting a national EDRR program. An asset inventory should include programs currently focused on addressing invasive species as well as those programs that could be cost-effectively modified to expand federal capacities for addressing invasive species. The results of the recent EDRR survey and additional information contained within this series of federal capacity assessments provide a useful starting point.
5. *Interagency budget* The asset inventory will enable NISC member agencies to develop a more accurate and useful EDRR cross-cut budget, one that can be used as a reference point for more effective leveraging of existing agency resources and development of multi-agency funding proposals to address common needs for additional resources. The US Office of Management and Budget (OMB) could take a leadership role in this process, guiding coordination and helping to optimize cost-efficiencies.
6. *Information accessibility* The capacity for federal agencies and their partners to effectively enact EDRR could be increased substantially simply by facilitating greater access to existing information. An online clearinghouse could be developed to curate the outputs of various detection reference materials (e.g., keys, watch lists), relevant analyses (e.g., target analyses, risk analyses, feasibility analyses), reports on the effectiveness of response measures, and training course curricula, for example. The clearinghouse could be informed by and/or integrated with databases being developed to meet some of these information needs (e.g., the Canadian Risk Assessment Database (https://www.invasivespeciescentre.ca/learn-about-invasive-species/risk-assessments, accessed 13 September 2019) and Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) Risk Assessment Database (https://www.glerl.noaa.gov/glansis/riskAssessment.html, accessed 13 September 2019).
7. *Decision support* Further effort is needed to determine what, how, and how effectively agencies are applying EDRR decision support tools. Ideally, decision support tools will be standardized across the agencies and their outputs made publicly accessible. Papers in this Special Issue provide guidance for incident command systems, watch lists, target analysis, and risk screening. Further work is needed for advance feasibility screening, including the provision of data on the dynamic socio-economic and cultural factors that influence response capacity. The latter is also needed to inform science-based social marketing

campaigns that address socio-economic and cultural barriers to response feasibility.

The federal government has a substantial and ever-growing responsibility to safeguard the nation from invasive species. To invoke the hackneyed but nevertheless meaningful phrase, "an ounce of prevention is worth a pound of cure," various government and non-government entities have been calling for greater attention to EDRR for decades. Although we propose a more systematic approach to EDRR than has been published elsewhere, our general findings are consistent with those of previous analyses and recommendations. The question thus remains, what is the difference that will make a difference? How can we transition from general concept to effective operational system? We hope that the answer emerges in the form of proactive leadership, cooperation, and engagement rather than a reactive and uncoordinated response to a potentially avoidable national crisis.

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References

Aquatic Nuisance Species Task Force (1994) Aquatic nuisance species program. Aquatic Nuisance Species Task Force, Washington, DC

Aquatic Nuisance Species Task Force (2002) ANSTF strategic plan (2002–2007). Aquatic Nuisance Species Task Force, Washington, DC

Aquatic Nuisance Species Task Force (2007) ANSTF strategic plan (2007–2012). Aquatic Nuisance Species Task Force, Washington, DC

Aquatic Nuisance Species Task Force (2012) ANSTF strategic plan (2013–2017). Aquatic Nuisance Species Task Force, Washington, DC

Aquatic Nuisance Species Task Force Asian Carp Working Group (2007) Management and control plan for bighead, black, grass, and silver carps in the United States. Aquatic Nuisance Species Task Force, Washington, DC

Beck KG, Zimmerman K, Schardt JD, Stone J, Lukens RR, Reichard S, Randall J, Cangelosi AA, Cooper D, Thompson J (2008) Invasive species defined in a policy context: recommendations from the federal invasive species advisory committee. Invasive Plant Sci Manag 1:414–421

Burgiel SW (2019) The incident command system: a framework for rapid response to biological invasion. Biol Invasions. https://doi.org/10.1007/s10530-019-02150-2

Burgiel SW, Foote G, Orellana M, Perrault A (2006) Invasive alien species and trade: integrating prevention measures and international trade rules. Center for International Environmental Law and Defenders of Wildlife, Washington, DC

Burgos-Rodríguez J, Burgiel SW (2019a) Federal legal authorities for the early detection of and rapid response to invasive species. Biol Invasions. https://doi.org/10.1007/s10530-019-02148-w

Burgos-Rodríguez J, Burgiel SW (2019b) Federal legal authorities: guidance for application to the early detection of and rapid response to invasive species. Biol Invasions. https://doi.org/10.1007/s10530-019-02149-9

Chapman D, Purse BV, Roy HE, Bullock JM (2017) Global trade networks determine the distribution of invasive non-native species. Glob Ecol Biogeogr 26(8):907–991

Climate and Natural Resources Working Group (2014) Priority agenda: enhancing the climate resilience of America's natural resources. Council on Climate Preparedness and Resilience, Washington, DC. https://obamawhitehouse.archives.gov/sites/default/files/docs/enhancing_climate_resilience_of_americas_natural_resources.pdf. Accessed 22 August 2018

Conservation of Arctic Flora and Fauna Working Group and Protection of the Marine Environment Working Group (2017) Arctic invasive alien species: strategy and action plan. CAFF and PAME, Akureyri

Crall AW, Renz M, Panke BJ, Newman GJ, Chapin C, Graham J, Bargeron C (2012) Developing cost-effective early detection networks for regional invasions. Biol Invasions 14:2461–2469. https://doi.org/10.1007/s10530-012-0256-3

Elizinga CL, Salzer DW, Willoughby JW (1998) Measuring and monitoring plant populations: Bureau of land management technical reference 1730-1, BLM/RS/ST-98/005 + 1730

Environmental Law Institute and The Nature Conservancy (2007) Strategies for effective state early detection/rapid response programs for plant pests and pathogens. Environmental Law Institute, Washington, DC

Executive Office of the President (1999) Executive order 13112, 64 FR 6183-6186, 8 February 8 1999

Executive Office of the President (2016) Executive order 13751, 81 FR 88609-88614, 5 December 2016

Federal Interagency Committee for the Management of Noxious and Exotic Weeds (2003) A national early detection and rapid response system for invasive plants in the United States: conceptual design. Federal Interagency Committee for the Management of Noxious and Exotic Weeds, Washington, DC

Fuller PL, Neilson ME (2015) The US geological survey's nonindigenous aquatic species database: over thirty years of tracking introduced aquatic species in the United States (and counting). Manag Biol Invasions 6(2):159–170

Hayes KR, Canaon R, Neil K, Inglis G (2005) Sensitivity and cost considerations for the detection and eradication of marine pests in ports. Mar Pollut Bull 50:823–834

Holland J, Kirkey JR, Reaser JK (2018) Protecting what matters: stories of success. National Invasive Species Council Secretariat, Washington, DC

Hussner A, Stiers I, Verhofstad MJJM, Bakker EM, Grutters BMC et al (2017) Management and control methods of invasive alien freshwater aquatic plants: a review. Aquat Biol 136:112–137

International Union for the Conservation of Nature (2000) IUCN guidelines for the prevention of biodiversity loss caused by invasive species. International Union for the Conservation of Nature, Gland

Invasive Species Advisory Committee (2017) Advanced biotechnology tools for invasive species management. National Invasive Species Council Secretariat, Washington, DC

Kamenova S, Bartley TJ, Bohan D, Boutain JR, Colautti RI et al (2017) Invasions toolkit: current methods for tracking the spread and impact of invasive species. Adv Ecol Invasions. https://doi.org/10.1016/bs.aecr.2016.10.009

Labs Conservation X (2017a) The innovation summit report. National Invasive Species Council Secretariat, Washington, DC

Labs Conservation X (2017b) The innovation summit report: annexes. National Invasive Species Council Secretariat, Washington, DC

Leung B, Lodge DM, Finnoff D, Shogren JF, Lewis MA, Lamberti G (2002) An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proc R Soc Lond 269:2407–2413

Lodge DM, Williams SL, MacIsaac HJ, Hayes KR, Leung B et al (2006) Biological invasions: recommendations for U.S. policy and management. Ecol Appl 16:2035–2054

Lodge DM, Simonin PW, Burgiel SW, Keller RP, Bossenbroek JM et al (2016) Risk analysis and bioeconomics of invasive species to inform policy and management. Annu Rev Environ Resour 41:453–488

Lyal CHC, Miller SE (2019) 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. Biol Invasions. https://doi.org/10.1007/s10530-019-02147-x

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences and control. Ecol Appl 10:689–710

Martinez B, Reaser JK, Dehgan A, Zamft B, Baisch D et al (2019) Technology innovation: advancing capacities for the early detection of and rapid response to invasive species. Biol Invasions. https://doi.org/10.1007/s10530-019-02146-y

McCullough DG, Work TT, Cavey JF, Liebhold AM, Marshall D (2006) Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period. Biol Invasions 8:611–630

McNeely JA, Mooney HA, Neville LE, Schei P, Waage JK (eds) (2001) A global strategy on invasive alien species. IUCN and the Global Invasive Species Programme, Gland

Meyers NM, Reaser JK, Hoff MH (2019) Instituting a national early detection and rapid response program: needs for building federal risk screening capacity. Biol Invasions. https://doi.org/10.1007/s10530-019-02144-0

Meyerson LA, Reaser JK (2002a) Biosecurity: moving toward a comprehensive approach. BioSci 52:593–600

Meyerson LA, Reaser JK (2002b) A unified definition of biosecurity. Sci 295:44

Meyerson LA, Reaser JK (2003) Bioinvasions, bioterrorism, and biosecurity. Front Ecol Environ 1:307–314

Morisette JT, Reaser JK, Cook GL, Irvine KM, Roy HE (2019) Right place. Right time. Right tool: guidance for using target analysis to increase the likelihood of invasive species detection. Biol Invasions. https://doi.org/10.1007/s10530-019-02145-z

National Invasive Species Council (2001) Meeting the invasive species challenge: national invasive species management plan. US Department of the Interior, Washington, DC

National Invasive Species Council (2003) General guidelines for the establishment and evaluation of invasive species early detection and rapid response systems. Version 1. US Department of the Interior, Washington, DC

National Invasive Species Council (2008) 2008-2012 National Invasive Species Council management plan. National Invasive Species Council, Washington, DC

National Invasive Species Council (2011) National Invasive Species Council crosscut budget summary. National Invasive Species Council, Washington, DC

National Invasive Species Council (2012) National Invasive Species Council crosscut budget summary. National Invasive Species Council, Washington, DC

National Invasive Species Council (2013) National Invasive Species Council crosscut budget summary. National Invasive Species Council, Washington, DC

National Invasive Species Council (2014) National Invasive Species Council crosscut budget summary. National Invasive Species Council, Washington, DC

National Invasive Species Council (2015) National Invasive Species Council crosscut budget summary. National Invasive Species Council, Washington, DC

National Invasive Species Council (2016a) National Invasive Species Council crosscut budget summary. National Invasive Species Council, Washington, DC

National Invasive Species Council (2016b) 2016–2018 National Invasive Species Council management plan. National Invasive Species Council, Washington, DC

Office of Technology Assessment (1993) Harmful non-indigenous species in the United States. US Congress, Washington, DC

Reaser JK (2019) Putting a federal capacities assessment to work: blueprint for a national program for the early detection of and rapid response to invasive species (EDRR). Biol Invasions. https://doi.org/10.1007/s10530-019-02177-5

Reaser JK, Waugh J (2007) Denying entry: opportunities to build capacity to prevent the introduction of invasive species and improve biosecurity at US Ports. IUCN, Gland

Reaser JK, Meyerson LA, Von Holle B (2008) Saving camels from straws: how propagule pressure-based prevention policies can reduce the risk of biological invasion. Biol Invasions 7:1085–1098

Reaser JK, Simpson A, Guala GF, Morisette JT, Fuller P (2019a) Envisioning a national invasive species information framework. Biol Invasions. https://doi.org/10.1007/s10530-019-02141-3

Reaser JK, Frey M, Meyers NM (2019b) Invasive species watch lists: guidance for development, communication, and application. Biol Invasions. https://doi.org/10.1007/s10530-019-02176-6

Redford KH, Campbell K, Dayer A, Dickman C, Epanchin-Niell R, et al (2017) Invasive animals in the US national parks. Natural Resource Report NPS/NRSS/BRD/NRR-2017/1564. National Park Service, Fort Collins, Colorado

Resnik JR (2018) Biodiversity under siege, invasive animals and the National Park Service: a state of the knowledge report. Natural Resource Report NPS/NRSS/BRD/NRR—2018/1679. National Park Service, Fort Collins, Colorado

Ricciardi A, Blackburn TM, Carlton JT, Dick JTA, Hulme PE et al (2017) Invasion science: a horizon scan of emerging challenges and opportunities. Trends Ecol Evol 32:464–474. https://doi.org/10.1016/j.tree.2017.03.007

Roy H, Peyton J, Aldridge DC, Bantock T, Blackburn TM et al (2014) Horizon scanning for invasive alien species with the potential to threaten the biodiversity of Great Britain. Glob Chang Biol. https://doi.org/10.1111/gcb.12603

Simberloff D (2003a) Eradication—preventing invasions at the outset. Weed Sci 51:247–253

Simberloff D (2003b) How much information on population biology is needed to manage introduced species? Conserv Biol 17:83–92

Simberloff D (2013) Invasive species: what everyone needs to know. Oxford University Press, New York

Simberloff D, Rejmánek M (eds) (2011) The encyclopedia of biological invasions. University of California Press, Berkeley

Simpson A (2006) Developing a national framework for invasive species early detection, rapid assessment, and rapid response. National Biological Information Infrastructure (NBII) Invasive Species Newsletter: Fact Sheet. US Geological Survey, Washington, DC

US Department of Homeland Security (2016) National response framework, 3rd edn. Department of Homeland Security, Washington DC

US Department of the Interior (2016) Safeguarding America's lands and waters from invasive species: a national framework for early detection and rapid response. US Department of the Interior, Washington, DC

US Department of the Navy (2015) Regional biosecurity plan for Micronesia and Hawaii, vol 1. University of Guam and the Secretariat of the Pacific Community, Hågatña

US Environmental Protection Agency (2008) Predicting future introductions on nonindigenous species to the Great Lakes. EPA/600/R-08/066F. National Center for Environmental Awareness, Washington, DC

US Forest Service (2004) National strategy and implementation plan for invasive species management, FS-805. US Department of Agriculture, Washington, DC

US Forest Service (2009) The early warning system for forest health threats in the United States: final draft. US Department of Agriculture, Washington, DC

US Forest Service (2013) Forest Service national strategic framework for invasive species management, FS-1017. US Department of Agriculture, Washington, DC

US General Accounting Office (2001) Invasive species: obstacles hinder federal rapid response growing. GAO-01-724. US General Accounting Office, Washington, DC

Waage JK, Reaser JK (2001) A global strategy to defeat invasive species. Sci 292:1486

Wallace RD, Bargeron CT, Moorhead DJ, LaForest JH (2018) Information management relevant to invasive species early detection and rapid response programs. National Invasive Species Council Secretariat, Washington, DC

Wallace RD, Bargeron IV CT, Reaser JK (2019) Enabling decisions that make a difference: guidance for improving access to and analysis of invasive species information. Biol Invasions. https://doi.org/10.1007/s10530-019-02142-2

Waugh JD (2009) Neighborhood watch: early detection and rapid response to biological invasion along US trade pathways. IUCN, Gland

Welch BA (2014) Introduction. In: Welch BA, Geissler PH, Latham P (eds) Early detection of invasive plants—principles and practices: US Geological Survey scientific investigations report 2012–5162. US Geological Survey, Washington, DC

Westbrooks R (2004) New approaches for early detection and rapid response to invasive plants in the United States. Weed Technol 18:1468–1471

Westbrooks R, Mehrhoff L, Madson J (2008) Invasive plants—coming to America: overview of the US national early detection and rapid response system for invasive plants: fact sheet. US Geological Survey, Invasive Plant Atlas of New England, Invasive Plant Atlas of the Mid-South. https://www.naisma.org/images/EDRR_FactSheet.pdf. Accessed July 10, 2018

Wittenberg R, Cock MJW (eds) (2001) Invasive alien species: a toolkit of best prevention and management practices. Centre for Agriculture and Bioscience International, Wallingford