REVIEW

Right place. Right time. Right tool: guidance for using target analysis to increase the likelihood of invasive species detection

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Abstract In response to the *National Invasive Species Council's 2016–2018 Management Plan*, this paper provides guidance on applying target analysis as part of a comprehensive framework for the early detection of and rapid response to invasive species (EDRR). Target analysis is a strategic approach for detecting one or more invasive species at a specific locality and time, using a particular method and/or technology(ies). Target analyses, which are employed across a wide range of disciplines, are intended to increase the likelihood of detection of a known target in order to maximize survey effectiveness and cost-efficiency. Although target analyses are not yet a standard approach to invasive species management, some federal agencies are employing target analyses in principle and/or in part to improve EDRR capacities. These initiatives can provide a foundation for a more standardized and comprehensive approach to target analyses. Guidance is provided for improving computational information. Federal agencies and their partners would benefit from a concerted effort to collect the information necessary to perform rigorous target analyses and make it available through open access platforms.

Keywords Detection · Early detection and rapid response (EDRR) · Invasive species · Target analysis

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Introduction

An invasive species is, "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" (Executive Office of the President 2016). The early detection of and rapid response to invasive species (EDRR) is a guiding principle for addressing invasive species in an effective and cost-efficient manner (Reaser et al. 2019a). In order to detect invasive species early in the invasion process, surveyors

(including inspectors at points of entry and field-based personnel) need to know the characteristics of the species of interest and be in the right place, at the right time, and with the right tool(s). If these criteria are not met, invasive species may bypass prevention measures, establish, spread, and cause adverse impacts to valued assets.

The *2016–2018 National Invasive Species Council (NISC) Management Plan* calls for an assessment of the capacity of federal inventory and monitoring programs to detect invasive species (NISC 2016). Reaser et al. (2019a) provide a general overview of the assessment findings and identify capacity building needs. In this complementary paper, we provide guidance for using target analysis as a tool to maximize the likelihood of invasive species detection through inventory and monitoring programs (collectively referred to as surveillance herein). We define target analysis as a strategic approach for detecting one or more invasive species at a specific locality and time, using a particular method and/or technology(ies). Target analysis is a key component of a holistic EDRR framework, as described by Reaser et al. (2019a, b, c).

Invasive species can be detected incidentally through opportunistic identification (Morrisseau and Voyer 2014) such as citizen science programs (Waugh 2009). However, the implementation of proactive prevention measures, including surveillance, is considered the most cost-effective approach to addressing invasive species (Lodge et al. 2006; Leung et al. 2002; McNeely et al. 2001). By enabling the development of robust and efficient statistical sampling designs, target analyses can maximize the effectiveness and cost-efficiency of invasive species detection when the target is known (i.e., a decision has been made to survey for specific invasive species) (Chin et al. 2018; Berec et al. 2015; Hoffman et al. 2016; Wang et al. 2014; US Forest Service n.d.; http://www.landscapetoolbox.org, accessed 24 September 2018). Target analysis is particularly advantageous for "finding the needle in the haystack" when the target is (1) a high risk to valued assets if it goes undetected, (2) mobile, (3) self-perpetuating, (4) rare (e.g., introduced population size is small), (5) a novel species that can have unpredictable behavior (such as dispersal or competition), and (6) subject to response measures that are substantially constrained with respect to time, funding, and other resources.

Target analysis, in various forms, is applied across a wide range of technical fields where the criteria listed above are applicable. Examples include sampling design and theory, particularly for high-risk contexts (De Gruijter et al. 2006); probabilistic risk analysis in bioterrorism (Ezell and Winterfeldt 2009); pandemic prediction surveillance and modeling (Watters and Biernacki 1989); and wildfire management (Schroeder et al. 2016; Khamukhin and Bertoldo 2016). Lessons learned from the use of target analysis components within these contexts could help advance invasive species applications.

Taleb (2007) regards rarity, extreme impact, and retrospective predictability as attributes of a "Black Swan," a theory he developed to explain the disproportional role of high-profile, hard-to-predict, rare events in human history. Related to the Black Swan concept, Lindenmayer et al. (2010) describe "ecological surprises" as events beyond either expected or unexpected results. Because the management of established and potential invasive species constitutes planning in light of uncertainty (Cook et al. 2014), applying target analyses to invasive species management may also benefit from applying event-prediction theory and associated models. For example, the arrival of invasive dreissenid mussels in Lake Powell (Colorado) and Lake Mead (Nevada/Arizona) is a Black Swan scenario. Although we now know that invasive mussels can thrive throughout the western US (Wong and Gerstenberger 2015), previous guidance (which had gone through rigorous peer review) on where to monitor for mussel introductions indicated very little to no risk in areas that later became heavily invaded (Drake and Bossenbroek 2004). This was an "ecological surprise" (Lindenmayer et al. 2010). Given the uncertainties inherent to any biological model, practitioners need to apply new information as it becomes available to better inform both iterative modeling and adaptive management decisions. This principle is reflected in arrows indicating information iteration in Fig. 1.

Drawing from the aforementioned fields of application, we regard target analyses as meta-analyses that integrate raw data, as well as information generated for and from other analytical components of a comprehensive EDRR system. Figure 1 depicts target analysis as generating information on when, where, and how to look for a given species or set of species based on the evaluation of key information inputs. It

Fig. 1 Target analysis: a conceptual framework. The figure depicts the input parameters, analytical approaches, and results (output) that can be used to guide a sampling strategy for specific species or groups of species in order to maximize the likelihood of their detection. Input data quantitatively characterize the biology and ecology of the target species, its distribution and movement patterns, as well as the methods and technologies used to detect the species in a context similar to the recipient ecosystem(s) of concern. The data analysis includes computations that use robust statistical sample survey design, modeling to forecast in space and time, and mapping to provide a spatial–temporal representation of locations for strategic sampling
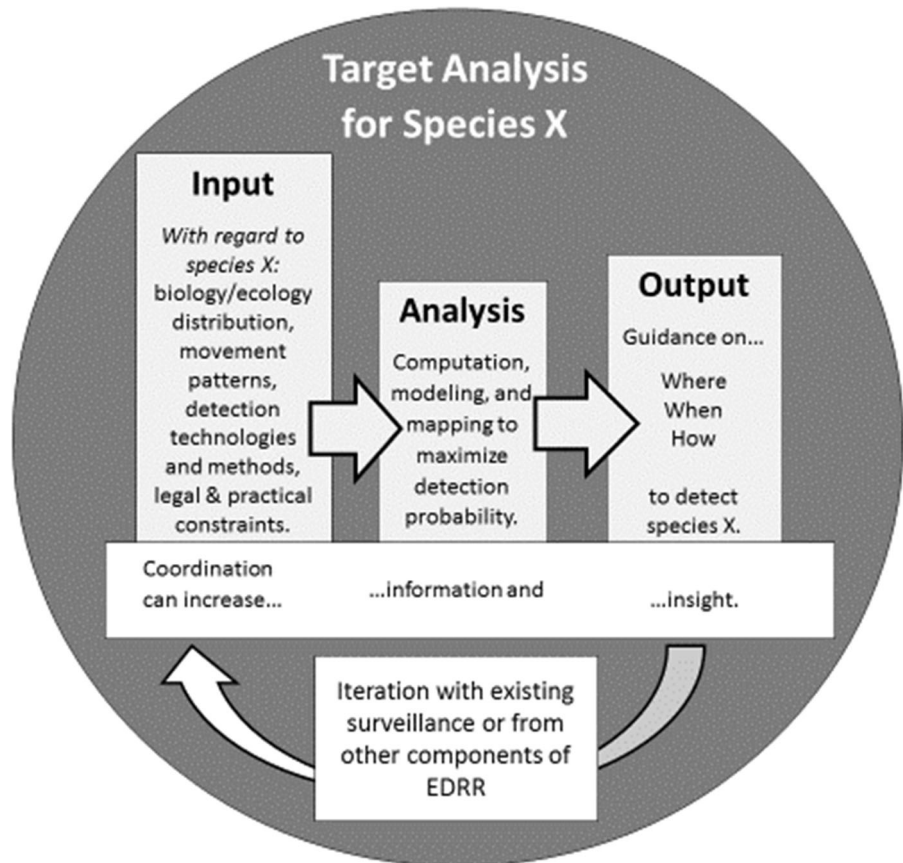
provides a conceptual framework for target analysis, depicting the input parameters, analytical approaches, and results (output) that can be used to guide a sampling strategy for specific invasive species or groups of invasive species in order to maximize the likelihood of detection. The essence of target analysis is to use the best available information, integrated through computation, modeling, and mapping to answer key questions pertaining to when, where, and how to most effectively and cost-efficiently detect invasive species. The data inputs must be as reliable (authoritatively verified) and as up-to-date as possible.

Currently, no standardized approach to target analysis exists. Those conducting target analyses optimally use the most robust analytical approaches and tools available to them and report their methods. Russell et al. (2017) provide a practical example of target analysis computations. They consider the characteristics of the species of interest, multiple devices/technique being used, and the time frame to optimize surveillance for invasive rodents on islands after an eradication has been attempted. Although they do not include spatial variables in their formula, they do recognize the importance of spatial considerations by noting that the parameters in their calculations will differ between sites and in different climates.

The computations that constitute target analysis are largely built on existing information and use statistical sampling theory (Russell et al. 2017; Berec et al. 2015; Hoffman et al. 2016; US Forest Service n.d.; http://www.landscapetoolbox.org, accessed 24 September 2018). Modeling helps extend estimates about the invasive species in space and/or time (Cook et al. 2019; Wang et al. 2014). Mapping is used to consider important geospatial information, jurisdictional boundaries, and logistical aspects of surveillance strategy. In addition to highlighting the flow of input, analysis, and output, Fig. 1 also emphasizes coordination and iteration for conducting target analysis.

The following are questions to consider when one conducts a target analysis. These questions are intended to help identify the data to be processed

through computational, mapping, and/or modeling approaches available to the analyst. For regulated species, analytical approaches must be consistent with the directives of relevant legal frameworks (Burgos-Rodríguez and Burgiel 2019).

Where?

1. What habitat(s) does the species occupy in its native range?
2. What resources (food, shelter, reproductive sites, etc.) is it attracted to?
3. What conditions and features (natural and human-constructed) promote or deter the invasive species?
4. How does the species spread by its own volition and in what territory/range size?
5. How can the species be transported, and what are the patterns associated with this mode of transport (i.e., what are the known, existing, or potential pathways)?
6. What are the most feasible interception points along this pathway?
7. How do 1-6 change through time (see When list)?

When?

1. What are the daily activity patterns of the species (diurnal, nocturnal, crepuscular)?
2. What are the weather-associated activity patterns for the species (temperature, moisture, etc.)?
3. What are the activity patterns of the species with regard to patterns in the availability of food, shelter, and other resources?
4. What are the activity patterns of the species with regard to the presence or absence of other species (predators, competitors, parasites, etc.)?
5. What are the seasonal activity patterns of the species (phenology, migratory patterns, population periodicity over years, etc.)?
6. When are the species most prevalent or likely to occur at the various steps of the invasion pathway?

How?

1. What visual, auditory, or other characteristics of the species facilitate detection?
2. What detection methods have been effective/ineffective in similar contexts?

3. What detection technologies have been effective/ineffective in similar contexts?
4. What are the most feasible detection points along the pathway?
5. How do the above (1–5) change according to time and location (see Where and When lists)?
6. How do authorities, policies, feasibility, and cost effectiveness influence application of the above (1–5)?

Federal agencies employing target analysis for invasive species EDRR, whether in name or principle, are largely doing so to increase detection rates at points of entry (pathway interception) and/or in known, potentially recipient ecosystems. In the points-of-entry context, special considerations for target analysis include (1) regulatory and policy directives that could influence method options, such as the Security and Accountability for Every Port Act (2006) and the US Department of Agriculture's (USDA) Agricultural Quarantine Inspection Monitoring program (USDA 2011) (see also Burgos-Rodríguez and Burgiel 2019); (2) the high volume of a wide diversity of conveyances and containers that could be moving invasive species as commodities or hitchhikers; (3) the dynamic nature of trade and travel patterns (Haack et al. 2014); (4) the advantage (over the broader spatial domain of recipient ecosystems) of very specific, known locations from which to monitor (US Department of Homeland Security and USDA 2003); and (5) the ability to include reliable information on the type, source, and movement history of the potential conveyance (e.g., baggage, cargo, trailered watercraft; USDA 2011). With regard to recipient ecosystems, special considerations for target analysis include the need to understand (1) pathway patterns and trends (i.e., how invasive species are entering and moving through the ecosystem) (USDA 2018); (2) how ecosystem characteristics vary over time and space; and (3) how species traits relate to these ecological patterns and trends (Brooks and Klinger 2012; Stohlgren and Schnase 2006).

To the best of our knowledge, no federal agency is *explicitly* conducting *comprehensive* target analysis for invasive species, and there is no overarching federal focus on target analysis as part of an invasive species EDRR framework. However, several agencies use components of target analysis and analytical approaches to develop invasive species sampling

strategies. These could be considered target analyses in concept, or aspects of target analyses. We provide five examples below:

Department of Homeland Security The National Agriculture Cargo Targeting Unit (NACTU) is an operational arm of the Agriculture Programs and Trade Liaison (APTL) co-located at the National Targeting Center. Under the Department of Homeland Security, US Customs and Border Protection (CBP) Office of Field Operation, APTL has established NACTU to improved CBP's agriculture quarantine targeting through multiple pathways to include cargo and passengers. NACTU operations analyze national quarantine activities and apply resulting trends to importation practices in multiple pathways in order to identify quarantine risks before they arrive. With a strong focus on pest exclusion and trade, NACTU identifies inconsistencies in importation trends and applies risk-based criteria to identify repeat violators and high-risk pathways. This makes agriculture exams more efficient, thereby acting as a force multiplier towards CBP's agriculture mission.

Department of Agriculture On an annual basis, USDA's Animal and Plant Health Inspection Service (APHIS) has been using aspects of target analyses to forecast the likelihood of detecting European gypsy moth (*Lymantria dispar dispar*) outside of the existing federal quarantine area. Because pathways for spread differ across space (from natural spread over relatively short distances to human-assisted spread over long distances), the gypsy moth model is regionalized to capture these different pathways (Cook et al. 2019). The resulting model output is used to guide sampling, directing more effort to high-probability locations (USDA 2014). Using measurements of heat accumulation (such as growing degree days) in phenology models that predict the emergence of the adult flying stage, APHIS targets trap placement for optimal pest detection across space and time (Sheehan 1992; Régnière and Nealis 2002).

Department of the Interior The US Geological Survey (USGS) is considering a target analysis approach to enhance detection of the invasive fungus (*Pseudogymnoascus destructans*; Pd) that is commonly known to cause white-nose syndrome when infecting bats (Jachowski et al. 2014; Rodhouse et al. 2012). The analytical approach leverages monitoring data to project the likelihood of at-risk bat species occurrence at unsurveyed locations and to inform the

timing of capturing bats in order to increase the chances of detecting Pd on susceptible bats.

The US National Park Service (NPS) has an extensive biodiversity inventory and monitoring program (Fancy et al. 2009). Invasive plant surveys and response are coordinated through their Exotic Plant Management Team (EPMTs). The Mid-Atlantic Inventory and Monitoring Network established a single platform where resource managers and support staff could access baseline information on natural resource inventory and monitoring, as well as information on observations and management actions from the EPMT and fire management staff (Dammeyer and Shedd 2017). The system can improve surveillance by providing documentation and maps of what has already been detected and treated as well as baseline ecological and disturbance information that can help inform future surveillance.

Inter-agency Together, the US Environmental Protection Agency (EPA) and US Fish and Wildlife Service (USFWS) are working with state agencies to evaluate approaches to the early detection of aquatic invasive species with the intent of establishing survey protocols and designing a process for routine evaluation of survey performance (Hoffman et al. 2016).

These exemplary programs can serve as a foundation on which to build a more holistic approach to target analysis within the US federal government and elsewhere. Agencies with responsibilities for invasive species detection could benefit from a standard approach to surveillance (intercept) data management and target analysis protocols. In keeping with the tenets of adaptive management (Buckley 2008), this would enable target analyses to be refined over time. By comparing targeted detections against baseline expectations, surveyors can determine if they are appropriately targeting the selected samples (Jarrad et al. 2015). The outcome of these analyses can be used to improve the quality of the target analysis and better optimize detection strategies (Hulme 2009). Artificial intelligence (machine learning) could also be used to identify detection patterns and trends and "train" target analyses to become more sophisticated for certain contexts and species (see Martinez et al. 2019).

Overall, the capacity for conducting target analyses can be improved through advancements in the quantity and quality of the information required for the analyses. In particular, this includes

1. Improvements in collection of and access to non-native species occurrence data (Reaser et al. 2019c),

2. Increasing our knowledge of species biology and ecology (Reaser et al. 2019b; Meyers et al. 2019),

3. Advances in invasive species detection technologies and data on their efficacy (Martinez et al. 2019; Kamenova et al. 2017; Lodge et al. 2006),

4. Standardization and expansion of other decision support tools, such as risk screening (Meyers et al. 2019), horizon scanning for strategic planning (Roy et al. 2015; Sutherland and Woodroof 2009), and dashboards for operational reporting [e.g., from business (Eckerson 2010) or human health contexts (Kunjan et al. 2018)] and

5. Increased awareness, communication, and coordination across agencies and with other monitoring programs [e.g., citizen science (Kamenova et al. 2017; Tulloch et al. 2013; Roy et al. 2012)].

Conclusion

Executive Orders 13112 (Executive Office of the President 1999) and 13751 (Executive Office of the President 2016) charge federal agencies with taking a cooperative, cost-efficient approach to addressing invasive species. They underscore the need to apply the best-available data, analytical models, and technologies to support decision-making. Target analysis is an underused, yet vital tool for preventing the introduction and spread of invasive species. The broader application of target analysis could improve collaboration in species surveillance (especially across jurisdictions), information sharing, analytical tool development, and technology advancement.

The guidance provided here is not meant to be prescriptive or comprehensive; it provides a starting point for advancing the development and application of target analysis for invasive species EDRR with a view towards more integrated and comprehensive EDRR efforts. Federal agencies and their partners would benefit from greater awareness of target analysis as addressed in theory and by other fields of practice. This could include an assessment of opportunities for strengthening and expanding use of target analysis within their EDRR programs (e.g., watercraft inspection stations), a concerted effort to expand target

analysis application where needed/warranted, ongoing improvements in the quantity and quality of information drawn upon for target analyses, and the communication of target analysis reports into an open-access clearinghouse for future reference. Collectively, these efforts could help increase early detection while maximizing the efficiency of existing or future invasive species surveillance efforts.

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