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Management in Practice

A workshop to advance invasive species early detection capacity of The Rapid Environmental DNA Assessment and Deployment Initiative & Network (READI-Net)

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Abstract

Early detection and rapid response (EDRR) can minimize the impacts of invasive species, which cost billions of dollars globally. To bolster EDRR across the United States, the U.S. Department of the Interior is working with the U.S. Geological Survey and other partners to advance a National EDRR Framework that strengthens tools, actions, and processes to find and eradicate invasive species before they establish and cause negative impacts. An important component of this framework is to strengthen molecular tools for detecting new invasions. The Rapid Environmental (e)DNA Assessment and Deployment Initiative & Network (READI-Net) project is developing automated eDNA sampling tools and processes to ensure that eDNA results are reliable for management decision-making, and information structures to deliver eDNA results to end-users. To improve the potential uptake of this molecular EDRR toolbox, READI-Net investigators met with a group of end-users, partners, developers, and subject-matter experts from federal agencies, tribes, universities, and an NGO representing state agencies from February 28 to March 1, 2023, in Moss Landing, CA. Here, we summarize the READI-Net project and the corresponding participant feedback.

Key words: eDNA, early detection rapid response, biomonitoring

Introduction

Aquatic invasive species have cost the global economy $345 billion dollars since 1960, with costs increasing exponentially over time (Cuthbert et al. 2021). Early detection-rapid response (EDRR) is a guiding principle for minimizing invasive species impacts in a cost-efficient manner (Reaser et al. 2020). The longer an infestation goes undetected and untreated, the more likely it is to establish, spread, and reach abundances capable of causing adverse impact. Control efforts become more expensive and less effective for larger and widespread populations. The need for a coordinated national EDRR framework in the United States was identified in federal planning documents (U.S. Department of the Interior 2016) and then further detailed in a Special Issue of *Biological Invasions* (Volume 22, 2020), which informed a blueprint to facilitate the collaboration, communication, cost-efficiencies, and innovations necessary for an effective national EDRR program (Reaser

2020). Recent funding from the Infrastructure Investment and Jobs Act (i.e., Bipartisan Infrastructure Law; BIL) of 2021 and multiple inter-agency, departmental, and bureau-specific strategic plans (e.g., U.S. Fish & Wildlife Service 2015; U.S. Department of the Interior 2021), have enabled the U.S. Department of the Interior (DOI) to go from blueprint to build.

Advancing a National EDRR Framework is a priority for the DOI, which leveraged a portion of BIL funding to implement a body of work that will build and enhance a nationally coordinated set of tools, actions, and processes to proactively find and eradicate new invasive species before they establish, spread, and cause harm (Figure 1). Initial investments were directed to U.S. Geological Survey (USGS) scientists to work closely with other DOI Bureaus and Offices, other Federal partners, States, Tribes, Territories, local resource management efforts, and nongovernmental organizations to bring together capabilities more effectively, efficiently, and collaboratively to undertake transformational approaches to accomplish EDRR outcomes. Among the specific projects is to advance molecular detection tools to aid in invasive species early detection within the transportation and living industry pathways of introduction and spread in the environment (Lodge et al. 2006).

The USGS project that was initiated to advance molecular early detection capacity for aquatic invasive species is called the Rapid Environmental (e)DNA Assessment and Deployment Initiative & Network (READI-Net). The READI-Net Project seeks to transition eDNA surveillance approaches from research to actionable science by developing autonomous eDNA samplers to improve detection rates, standardized procedures to ensure confidence in eDNA results, and information systems to communicate eDNA results to decision-makers (Figure 2). READI-Net is largely focused on improving and supporting autonomous eDNA sampling technology (i.e., robots) in collaboration with the Monterey Bay Aquarium Research Institute (MBARI), which has pioneered molecular sampling and storage robots (Scholin et al. 2017). To realize the potential of eDNA robots for EDRR, READI-Net is also developing capacity to ensure that eDNA results, beyond just those provided by robots, provide reliable sources of data for decision-making. These are necessary steps required for efficient uptake of eDNA data into federal management for regulatory decision making and for priming positive feedback between innovations in eDNA technology and management (Morisette et al. 2021; Lodge 2022).

READI-Net workshop

READI-Net Project leads convened a workshop at MBARI in Moss Landing, CA on 28 February – 01 March 2023. This workshop brought together a cross-section of end-users, partners, developers, and subject-matter experts from federal agencies, and included four participants from tribes, universities, and NGOs representing state agencies. The workshop engaged participants on the READI-Net lines of work (tasks) and provided an opportunity for relationship- and trust-building. Partner uptake of scientific findings and

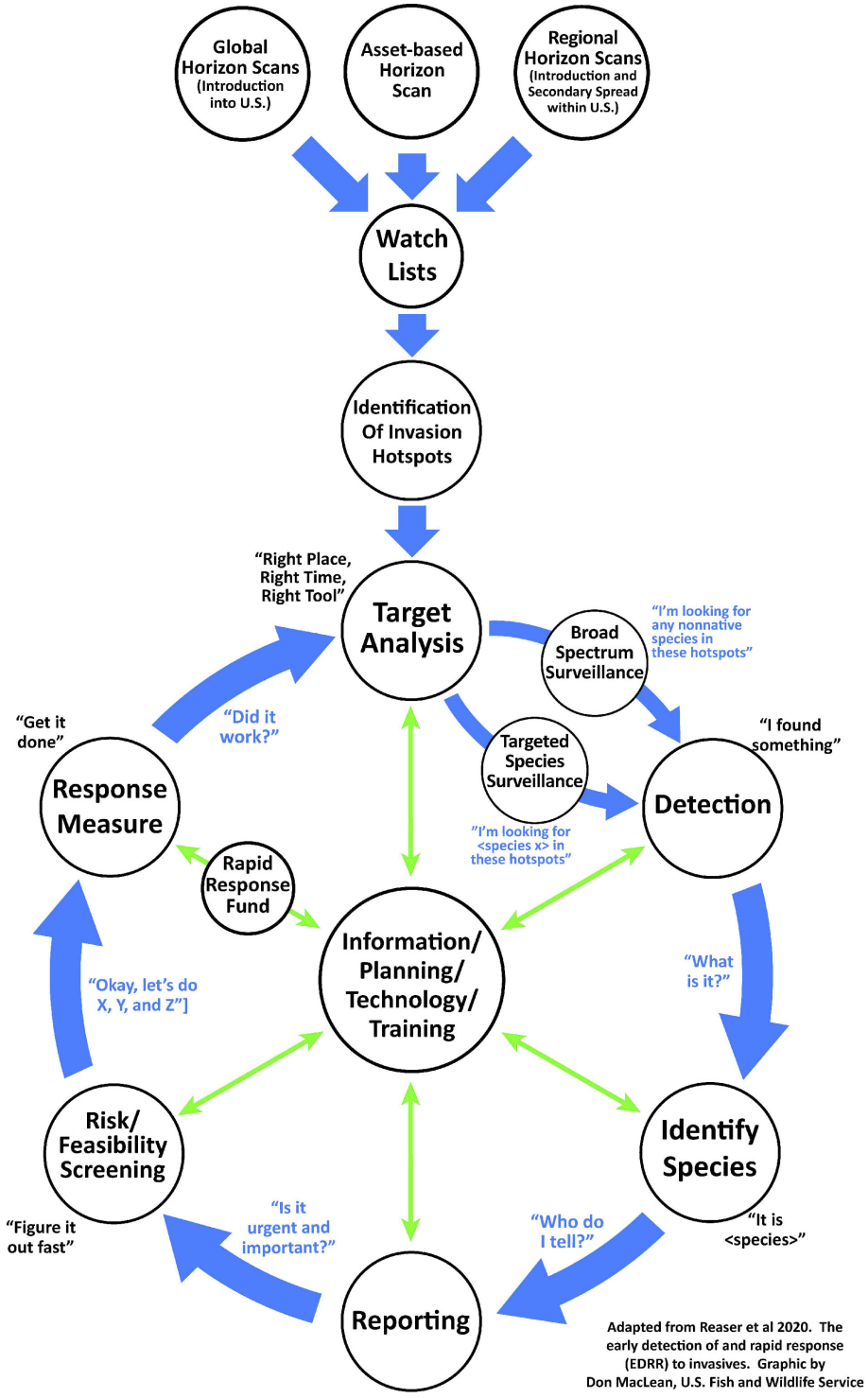

Figure 1. The National Early Detection Rapid Response framework developed by the U.S. Department of the Interior Invasive Species Task Force. Open circles represent the components to be enacted for effective early detection and rapid response of invasive species. The associated commentary reflects the primary questions, observations, and directives that the process from one component to the next. At the core of the process, are the informational inputs necessary for management decision-making.

tools requires trust-building and extended dialogue with scientists through approaches such as coproduction and translational ecology (Aylagas et al. 2020; Bamzai-Dodson et al. 2021). On day 1, we focused on development of a new eDNA robot by MBARI and discussed robot design features that would

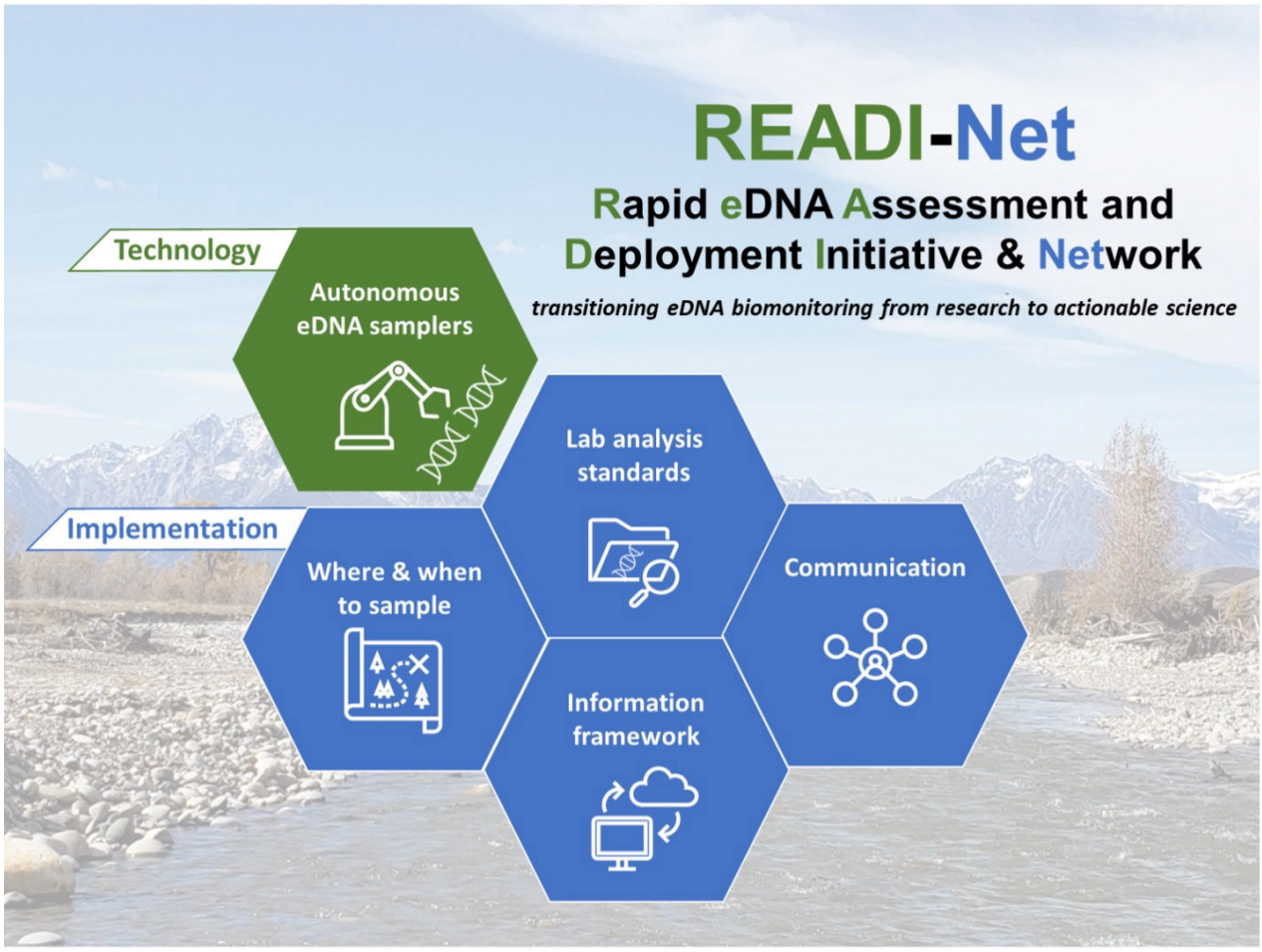

Figure 2. The Rapid Environmental (e)DNA Assessment and Deployment Initiative & Network (READI-Net) project components being developed to support molecular detection of invasive species. Molecular tools, like eDNA sampling, are sensitive and cost-effective for early detection of invasive species and are one component of the National Early Detection Rapid Response framework.

add value to workshop participants' EDRR research and management programs. On day 2, READI-Net principal investigators briefed participants on the tasks conducted to effectively incorporate eDNA robots into surveillance networks and to ensure that eDNA results are reliable sources of data for decision-making. Participants provided insight on task prioritization, gaps, and redundancies. Below we summarize tasks and participant feedback.

Task 1: Autonomous eDNA sampler development

Portable eDNA robots can be distributed across space in a highly networked fashion and collect numerous eDNA samples over time, and therefore have the potential to serve as efficient and sensitive early detection tools (Truelove et al. 2022). MBARI's current generation of autonomous sampling robots can be deployed only at a limited number of sites – they are complicated, expensive, and heavy because their initial design specifications were optimized for prolonged subsurface deployments in the open ocean (Scholin et al. 2017). READI-Net is working with MBARI to develop simpler, smaller, lighter, and less costly eDNA robots for other applications. Workshop participants suggested minimum viable requirement specifications for eDNA robot

hardware (i.e., components associated with collecting, filtering, and preserving eDNA water samples) and eDNA robot software (i.e., program interface used to communicate between the user and the hardware). Suggested specifications included design aspects to maximize detection probabilities (e.g., high sample capacity), sample integrity (e.g., decontamination rinses), and ease of use (e.g., two-way communication).

Task 2: Where and when to sample

The supply of eDNA robots and the number of samples that a robot can collect per mission are limited and therefore selection of sample location and frequency are extremely important. Many EDRR surveillance emergencies will not have adequate time to collect pilot data to optimize sampling. General models that describe how an eDNA signal changes over space and time (i.e., fate and transport dynamics) are needed to inform study design. Intensive effort has been invested to develop site × taxa specific models (e.g., Laporte et al. 2020), but models are data hungry, computationally intensive, and are often impractical and ineffective when applied to novel situations. To develop generalizable eDNA sampling strategies, we are building upon simpler, hydrology-based eDNA transport models of Carraro et al. (2018) and Carraro et al. (2021) which couple first-order formulation of eDNA decay with geomorphology and hydraulic properties of river networks. Experiments that introduce known concentrations of novel eDNA into a range of river sizes (e.g., 2^{nd}–6^{th} order) will be used to evaluate the usefulness of this more general modeling approach to field applications. Participants were concerned that models would not be applicable to invasion hotspots, like reservoirs. In response to this feedback, we are exploring other model specifications for more complex systems while field testing the performance of the expanded model from Carraro et al. (2018). For example, we will expand the Carraro et al. (2018) model to incorporate the variation in eDNA transport and detection along both the direction of flow and along the width of the stream. We also plan to add an occupancy process to the model to better accommodate the ecology of new invaders that have not fully saturated their preferred habitat, as the current Carraro et al. (2018) model assumes the focal species lives ubiquitously throughout the river network, but at different densities.

Task 3: Lab analysis standards

The usefulness and reliability of READI-Net deliverables hinges on our ability to standardize all aspects of the eDNA sampling process and ensure quality results. Routinely applied standards to provide quality assurance and controls (QA/QC) to field and lab workflows are a critical need for uptake of eDNA data for decision-making (e.g., Ferrante et al. 2022). Without these standards, end-users may continue to question the validity of eDNA results

that are often difficult to corroborate with non-molecular methods (e.g., Fediajevaite et al. 2021; Kelly et al. 2023). To move beyond this impasse, READI-Net seeks to identify pressure points in eDNA workflows that are sensitive to lab variation and therefore require standardization to ensure repeatability and reproducibility. READI-Net is working with the iTrackDNA program based out of Canada to conduct lab workflow intercalibration exercises across 17 labs. Intercalibration exercises begin with assessments with limited variables to test under ideal conditions and progress to more complex assessments under field conditions. Based on these results and additional intercalibration exercises with READI-Net labs, we will standardize workflow pressure points to reduce interlaboratory variation in eDNA results. This process will guide the development of a proficiency testing framework that can be used to evaluate READI-Net lab performance and will likely be broad enough to use in external lab networks. Partners agreed that the most crucial step for use of eDNA sampling in management is the development of field and laboratory standard operating procedures to ensure QA/QC across groups (i.e., results should not vary due to the person/group collecting and analyzing the samples).

Task 4: Information framework

EDRR effectiveness depends on the availability of and access to accurate, up-to-date information. To ensure accuracy and provide access, READI-Net is developing information tools that enable cradle-to-grave tracking of samples and their related data across multiple labs in real time. The USGS eDNA Laboratory Information Management System (LIMS) is being designed to (1) facilitate communication among the READI-Net labs, (2) ensure the labs are all collecting similar data, (3) improve sample tracking and lab efficiencies while reducing error rates, and (4) create an interoperable data communication platform that will allow for efficient knowledge transfer within labs, among labs, within the USGS, and among the various partners and general public. The end result will allow for the linkage of data for an eDNA sample from its initial creation to its final archival storage location across multiple labs and the sharing of the sample status, data, and metadata to partners through automation, mapping, and reporting. Having this framework in place allows users to coordinate sampling tracking, data sharing, and reporting of results while simultaneously demonstrating professional data standardization, transparency, and communication between researchers and partners. A lack of careful coordination risks lost, missing, or incomplete data, slow quality control processes, slow responses to collaborators, and incorrect results or interpretation. Records with errors can be excluded or corrected for downstream analyses and much of the quality assurance and control processes can be automated. The centralization of data and results allows researchers and partners to respond in nearly real time. We received affirmation from partners that this is a critical task, and that we are on the right track.

Partner identified gaps

While partners who attended the workshop were supportive of or already implement eDNA technology, they recognized that a lack of widely accepted standards and the potential implications of basing decisions on false positives or negatives causes apprehension among invasive species managers. Nonetheless, partners expressed excitement about the potential of eDNA sampling and its usefulness at critical invasion pathways, such as ports of entry. The gaps highlighted by partners primarily centered around communication strategies for results, especially for samples with unexpected detections. It is important that jurisdictional boundaries are not crossed and thus, we plan to work with partners to customize communication plans. Another gap identified by partners included a need for researchers to seek input from multiple agencies regarding the standardization and communication processes. Communication plans can provide transparency on the status of the science, strengths, and limitations of the specific applications, and clarify the role of all pertinent individuals in the flow of eDNA results from the lab to the public (Stein et al., 2023).

Next steps

The uptake of molecular approaches into invasive species management practices has been infrequent and slow (Darling 2015; Lodge 2022). Reasons for limited uptake are many but can be distilled to poor communication about the state of the science, lack of trust in the accuracy and reliability of the data, and limited integration of decision-makers in the research and development process (e.g., Darling 2015). READI-Net tasks directly address these criticisms and to increase the likelihood of uptake, further investments in communication and partner engagement are critical next steps.

Science communication has traditionally assumed that increased scientific literacy and more accurate and compelling facts will change decision-maker attitudes, but the evidence indicates otherwise because the human brain processes complex information sub-optimally (Toomey 2023). Decision-makers often rely on knowledge experienced by themselves or those in their social network to form beliefs, so the process of participation can be an effective way to shift attitudes (Cvitanovic and Hobday 2018; Toomey 2023). Implementation provides an opportunity to create and identify positive experiences (i.e., "bright spots"; Cvitanovic and Hobday 2018) that can be shared within and among social networks. Given these insights from cognitive science, we consider pilot implementation of the READI-Net program with local partners as a strategic way to increase the likelihood of eDNA sampling uptake into EDRR management practices.

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Authors' contribution

DNJ, KRC, and AJS all contributed to the writing and editing of the manuscript.

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