Minnesota Aquatic Invasive Species Research Center

2021

Legislative Report

Recommendations for establishing a statewide surveillance and early detection system for aquatic invasive species

Recommendations for establishing a statewide surveillance and early detection system for aquatic invasive species.

Legislative Request:

$510,000 the first year and $510,000 the second year are from the heritage enhancement account in the game and fish fund for grants to the Minnesota Aquatic Invasive Species Research Center at the University of Minnesota to prioritize, support, and develop research-based solutions that can reduce the effects of aquatic invasive species in Minnesota by preventing spread, controlling populations, and managing ecosystems and to advance knowledge to inspire action by others. Of the first year amount, $100,000 is to develop, in conjunction with the commissioner of natural resources, the commissioner of the Pollution Control Agency, counties, and other stakeholders, recommendations for establishing a statewide surveillance and early detection system for aquatic invasive species. By March 1, 2020, the Minnesota Aquatic Invasive Species Research Center must submit a report and recommendations to the chairs and ranking minority members of the legislative committees and divisions with jurisdiction over environment and natural resources policy and finance. The report must include recommendations on all of the following:

> (1) the most effective structure for a statewide surveillance and early detection system for aquatic invasive species;
>
> (2) whether to employ eco-epidemiological models, optimized decision models, or related tools as a mechanism for determining how best to deploy limited resources;
>
> (3) how the statewide system should be funded and at what levels; and
>
> (4) regulatory, policy, and statutory changes that would be needed to fully implement the statewide system.

The base amount for this appropriation in fiscal year 2022 and later is $410,000.

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Executive Summary

Aquatic invasive species (AIS) are one of the greatest threats to preserving Minnesota's natural aquatic resources, requiring effective surveillance and early detection to mitigate the threats posed by AIS.[1–3] In this report, we identify key components of a statewide surveillance and early detection system including, Surveys and Inspections, Partnerships and Communication, Education, Research, and Training, and Evaluation and describe these further in Section I. We address the use of eco-epidemiological and other decision support models to allocate limited resources in Section II. We then discuss the gaps and opportunities that exist in surveillance and early detection efforts currently conducted in the state in Section III and conclude the report in Section IV with recommendations on funding and regulatory modifications to support an effective statewide surveillance and early detection program, summarized below.

1. **Develop a statewide AIS surveillance and early detection plan-** Based on the framework described in Section I of this report and conversations with stakeholders, we recommend the development and implementation of a statewide AIS surveillance and early detection plan that will provide guidance to all stakeholders on surveillance and early detection activities, further cooperation, and increase the efficiency of current efforts. The development of this new plan should be done in cooperation with all relevant stakeholders to ensure the purpose, objectives, and evaluation strategies are supported.

2. **Establish a statewide database for AIS efforts-** In addition to the statewide AIS surveillance and early detection plan, we recommend the establishment of a statewide database to collect, archive, and share information regarding AIS surveillance and early detection efforts across the state. Currently, there is limited centralized information regarding AIS efforts made by state and county managers, researchers, and other stakeholders in Minnesota. Having a comprehensive database of AIS efforts will inform AIS decision making and help in the coordination of AIS efforts.

3. **Increase and/or adjust funding distribution-** As aquatic invasive species spread and their impacts continue to grow, so does the need for funding to address the problem. In times of financial stability, increased funding will ensure continued growth and development of robust and responsive programs. However, in times of economic distress, shifting the focus towards maximizing efficiency of current funding can support sustainable programmatic growth. We recommend increasing and/or restructuring the current AIS Prevention Aid funding allocation model to account for a risk-based allocation approach. In addition, the new funding model should support the implementation of local activities of the statewide AIS surveillance and early detection plan described in this report.

4. **Strengthen communications to foster regional coordination-** Coordinated management efforts for issues as complicated and widespread as AIS are critical. All stakeholders involved in AIS efforts must recognize that the management of AIS is a shared responsibility, and ineffective or underfunded efforts in one jurisdiction can affect the success of programs in neighboring jurisdictions. Fostering regional and statewide collaborations between the

diversity of stakeholders involved with AIS issues can boost efficiency and promote effective use of resources.

5. **Strengthen the definition of terms associated with AIS, surveillance, early detection, and rapid response of AIS-** Statutory definitions serve as key thresholds to our understanding of legislation. They can intentionally or unintentionally narrow or widen a statute's scope of understanding. In addition, statutory definitions can help unite heterogenous legislative audiences. As such, making the language more explicit for surveillance, early detection, and rapid response activities influences prioritization of and resource allocation for these activities.

Introduction

An invasive species is a non-native species whose introduction causes or has the potential to cause harm to the economy, environment, or human health.[4] Invasive species are a growing concern across the globe, leading to losses in biodiversity, disrupted ecosystem processes, and impacts on agriculture, forestry, fisheries, and international trade. Species invasions are facilitated through recreation, trade, natural pathways of spread, and other economic drivers, suggesting that the impact of AIS will continue to grow. While preventing the introduction of an AIS is the first line of defense, a strategic surveillance and early detection plan, coupled with efficient cost-effective responses,[5–7] are critical to containment and long-term control.[8–10]

Surveillance is broadly defined as the systematic collection and analysis of outcome-specific data, meaning that the data are collected with the intent to plan, implement, and evaluate management activities. Surveillance approaches are rooted in public health,[11] with the first public health surveillance activities recorded in 3180 B.C. in Egypt.[12] Since then, surveillance has been used for various purposes, including the detection of non-communicable diseases,[13,14] to manage environmental pollution,[15] to detect outbreaks of infectious disease,[16–19] and the presence of invasive species.[20–22] In the context of AIS, surveillance sampling may be designed to collect data which can be used in a variety of ways, including:

- Detect invasions
- Document the distribution and abundance of an invasive species within and across units of interest (e.g., lakes)
- Generate hypotheses about pathways of spread
- Evaluate management strategies, including prevention
- Assess the safety of control strategies and response procedures
- Identify research needs and facilitate research and a variety of planning activities
- Monitor evolutionary changes in the invasive species of interest

Broadly speaking, the sum of the surveillance activities comprises a statewide surveillance system, which should begin with a clear understanding of the purpose or objectives of the system. Additionally, to maximize their efficacy and efficiency, both the surveillance system and sampling strategies must be designed with careful consideration of species' behavior, habitat preferences, and ability to invade new locations.[19,20]

Early detection is a component of surveillance, intended to support rapid response efforts that will minimize the impacts of an AIS through containment or control, and in some cases, eradication. It is important to note that successful eradication of any population is challenging and often impossible with current technologies. Even with future technologies that may more effectively kill AIS in open-water environments, eradication would require proper planning and commitment to successfully impact the entire population, remove them faster than they reproduce, minimize non-target impacts, and prevent reinvasion.[23] Currently, no AIS have been eradicated in Minnesota, notwithstanding numerous attempts. Despite these challenges, early detection to support rapid response remains an essential component of effective management. There have been numerous examples where small populations were successfully contained, or interventions were implemented to meet management goals. Furthermore, recent technological advances, novel use of methods, and knowledge gained from successful and unsuccessful eradication campaigns worldwide continue to fuel advancements in this area.[23,2424,25]

The purpose of this report is to support statewide surveillance and early detection efforts by 1) Suggesting a framework for coordination and enhancement of current efforts, 2) Providing guidance on the use of eco-epidemiological and decision support tools in resource allocation, and 3) Outlining funding and regulatory opportunities that could support this framework.

The recommendations in this report were developed in a multidisciplinary manner incorporating principles of surveillance from ecology, invasion biology, and epidemiology with information gained through a review of pertinent literature, publicly available government documents, and through conversations with stakeholders (see acknowledgements for full list).

Background: Key concepts of surveillance

Surveillance systems may be classified as either active or passive (**Figure 1**). Most observations of AIS infestations rely on passive reporting or reports made by members of the public.[26,27] Passive surveillance has many advantages, such as being low cost and engaging many potential observers; however, the geographic coverage is typically unknown, and the expertise among observers is highly variable.[2] While passive reporting can be enhanced through public education and awareness campaigns, passive surveillance typically yields results that underestimate the severity of infestations and often fails to identify invasions in a timely manner.[3] On the other hand, active surveillance systems can validate passive reporting, ascertain the extent of an invasion, and allow for robust inference about AIS prevalence, but it can be resource-intensive and require strategic planning. Since resources are often limited, active surveillance systems are frequently used for targeted surveys of specific species, over discrete periods of time or regions, and can be used to inform more efficient risk-based passive surveillance approaches.

Surveillance		
	Passive	Active
Purpose	>To access trends >To identify risk factors for prevention and control	>To validate passive surveillance systems >To loosely track new invasions
Pros	>Inexpensive >Can cover large areas	>More accurate and complete data >Can produce early and timely data
Cons	>Under reporting >Incomplete data	>Can be resource intensive >Methodology must be well-developed

Figure 1. A comparison of passive and active surveillance.

Unit of analysis

The unit of analysis is the entity under consideration for which the findings of the survey are relevant. The unit of analysis differs from the unit of observation, which is simply the entities you are observing or measuring (e.g., adult zebra mussel shells), which may or may not differ from the unit of analysis. Units of analysis in AIS surveillance may be lakes, waterbodies, boats, or higher-level units (e.g., chain of waterbodies, counties, states, or countries). Moving forward in this report, we will assume that the unit of analysis is the waterbody because infestation status is widely tracked and responded to by waterbody.

Time frame for detection

Early detection implies that there is a target time frame for detection; however, this can be difficult to define. An operational definition for this report may be defined as surveillance for the presence of AIS prior to establishment so that potential rapid response efforts are most efficient and effective at controlling or limiting spread to additional waterbodies. We acknowledge that "*early*" is context-specific, relating to a particular target species' invasiveness, its detectability, and the ability of managers to respond effectively. In practice, a species-specific surveillance program should have a clearly defined target time frame to evaluate the system's performance. Because there may be minimal signs of the AIS during the lag period, despite its ability to spread (**Figure 2**), the target time frame should start from the moment the AIS is detectable while considering the methods used for detection. A longer time frame may result in a higher prevalence of the AIS, making detection easier but management more difficult.

Within this report, we use the terms *surveillance* and *early detection* with respect to AIS as strategic approaches for identifying AIS occurrences, with the intention of preventing and quantifying establishment, spread, and harmful impacts. This approach is in line with the larger context of AIS management because data gathered from early detection efforts help inform management responses.[28] Surveillance and early detection are typically coupled, in concept, to rapid response; however, in this report, we focus on surveillance and early detection only, with the understanding that these efforts must generate a rapid response to successfully control an AIS once it has evaded prevention efforts.

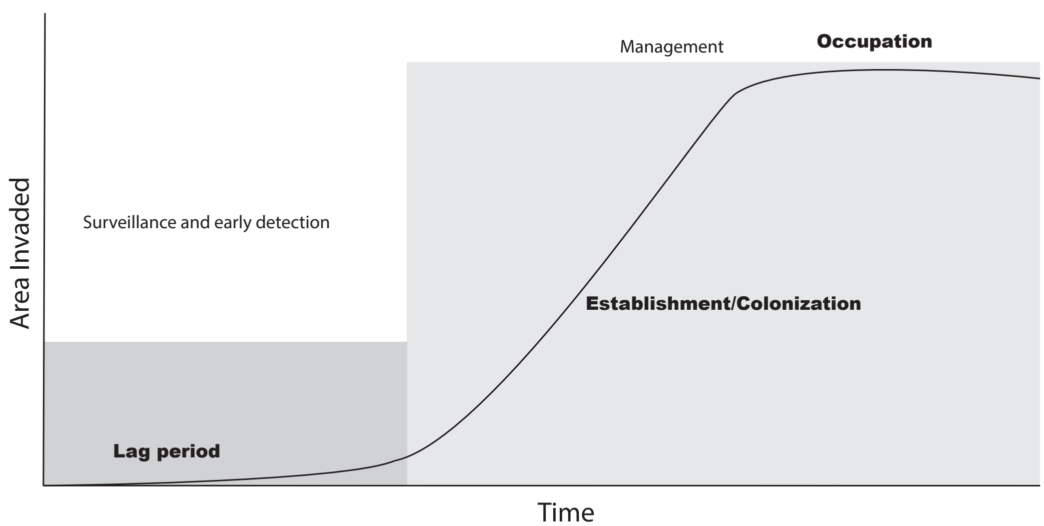

Figure 2. Invasion process for aquatic invasive species.

Sensitivity

Surveillance sensitivity is commonly used to measure the performance of surveillance in different contexts.[29–31] The sensitivity of surveillance activities measures their ability to detect the presence of an AIS (within the specified time frame in the context of early detection) and can be defined for a sample (sample sensitivity) or a survey (survey sensitivity). Sample sensitivity describes the probability of a sample to detect a population that is present at the sampling location,[32] and survey sensitivity is the probability of detecting a population present in the survey area or waterbody.[32] For early detection to be successful, the waterbody that is first infested must be included in the surveillance system, it must be surveyed in the appropriate time frame, and the method used for detection must be adequate for detecting the AIS in a life or population stage that is early enough such that development of a sustainable population can be prevented. Imperfect sensitivity may lead to false negatives, where a lake is inaccurately classified as un-infested, which may lead to undetected growth and spread of the AIS population.

Specificity

Specificity is another measure used to assess the performance of surveillance. Specificity describes the ability of a sample or survey to correctly identify the *absence* of an AIS. When the purpose of surveillance is to demonstrate that a waterbody is free from AIS, imperfect specificity may lead to false alarms, inaccurately classifying a lake as infested, leading to time- and resource-intensive follow-up investigations. Likewise, when the intention of the surveillance activity is to monitor or accurately assess the severity of an infestation, imperfect specificity may overestimate abundance and distribution. For example, environmental DNA (eDNA) is a tool that searches for genetic material to identify the presence of species. It has a high sensitivity and is particularly powerful when aiming to detect species at low abundance.[33] But when eDNA has been applied to AIS,[34–36] it has proven problematic for achieving high levels of specificity from environmental samples with low amounts of DNA or when needing to distinguish between closely related taxa;[37] potentially making it a more ideal tool for identifying new infestations versus monitoring the severity of existing infestations.

Types of surveillance

There are many more-specific types of surveillance, beyond the broad categories of active and passive surveillance. An optimal surveillance program would include a variety of surveillance approaches that form an integrated and dynamic system built upon ongoing data collection and real-time analysis to inform risk management.[38] This should drive policy and management activities that are continuously evolving and adapting to new information.[38]

Public reporting

Public reporting is a form of passive surveillance that has been used to identify new infestations of AIS. The public has been essential to informing the current know distribution of many AIS in Minnesota, playing a critical role in reporting new detections and preventing AIS in their communities.[39] However, public reporting comes with unique challenges associated with human behavior and introduces biases to the results.[27] For example, individual property owners participating in surveillance activities on waterbodies adjacent to their properties may only consider the impacts of detection on that waterbody rather than landscape-level impacts, leading to gaps in available data.[39] Recreational boaters also report AIS observations; however, their level of AIS awareness is highly variable and accurate detection requires prior knowledge. Public reporting efforts can be maximized with effective coordination, communication and educational programming.

Syndromic surveillance

Syndromic surveillance refers to a collection of approaches that aim to detect the introduction of an AIS based on statistical pattern analysis instead of direct observation of the invader. Damage or ecosystem changes consistent with presence of an AIS may be the first indication that an invasion has occurred.[40] The objective of syndromic surveillance is to identify AIS early, before they are observed using traditional detection methods, to mobilize a rapid response to increase efficiency and efficacy.[41]

Periodic surveys

Periodic surveys are conducted at a regular interval, but often do not attain full coverage of an area of interest or landscape scale and are rarely conducted frequently enough to reach the target time coverage needed to meet the standards of early detection as described above. Periodic surveys have been used to detect new populations of AIS or to monitor the spread of existing populations.

Risk-based surveillance

Risk-based approaches have been used in a wide variety of fields, including ecology, environmental science, and animal and public health.[1,3-5] Risk-based surveillance can be defined by the allocation of surveillance activities guided by the probability of an occurrence. It has grown in popularity over the last two decades[5] due to its ability to increase efficacy and efficiency. In this context, *risk* is based on the concept of probability theory and expectation that, while an individual event may be random, repeated events have a tendency to form patterns that allow for accurate predictions. It is critical to note that there is a distinction between *risk-based surveillance* and *risk-based sampling,*[29] as risk-based surveillance is built upon concepts of risk to design surveillance programs which may, for example, prioritize surveillance efforts across different locations or pathways. Conversely, *risk-based sampling* refers to the consideration of different characteristics or conditions that increases the likelihood that an introduction will occur, when determining the sampling effort allocated to different locations (or waterbodies) of risk represented by the units of analysis at the landscape level.

Probability theory is useful in planning and interpreting outputs of surveillance activities but must be used in a way that is in line with surveillance purposes. For example, if the objective of a surveillance program is to detect *all* AIS introductions, all units of interest (e.g., waterbodies or counties) must be under surveillance, or else a lower-risk unit would allow for an incursion to go undetected. But since resources are limited, risk can be used to prioritize resources to improve surveillance. So, while passive surveillance allows for high (area and temporal) coverage, the sensitivity may be quite low, leading to sub-optimal reporting. Investing in targeted high-risk areas would have a greater impact on surveillance sensitivity than increasing the investments in low-risk units.[29,42] A critical question that arises when considering risk-based surveillance is, "Where are the high-risk units?" We address this question further in Section II.

Sentinel surveillance

Similar to risk-based surveillance, sentinel surveillance involves using a limited number of waterbodies, or locations within a waterbody, with an elevated probability of AIS introductions to collect high-quality data. However, unlike risk-based surveillance, sentinel surveillance requires selecting waterbodies that are representative of the entire surveillance area, such that the results can be generalized to a larger surveillance area. Data collected in a well-designed sentinel system can be used to detect trends, identify new invasions, and provide an economical alternative to other active surveillance systems.[42] Minnesota's Sentinel Lakes Program (MSLP) is an example of sentinel surveillance that collects intensive and long-term data on physical, chemical, and biological changes in Minnesota's lakes.[43] The MSLP comprises 25 lakes across geographic locations, trophic statuses, and ecoregions.

Success stories in Minnesota

Zebra Mussels detected in Bone Lake

On May 28, 2019, a Washington Conservation District employee found six juvenile zebra mussels attached to a stick beneath the public access dock on Bone Lake. The detection was part of the county's weekly surveillance protocol developed in collaboration with the Minnesota DNR. The survey of that dock was negative the previous week, indicating that the juvenile population was recently introduced. Immediately after detection, the northern shore of Bone Lake was intensively surveyed for zebra mussels, and in the following days, the Emmons and Oliver Resources staff members, Minnesota DNR dive team, and Blue Water Science conducted over 70 hours of surveys, all of which resulted in no further detections of zebra mussels. A 10-day copper sulfate treatment was initiated on June 17, and staff continued their surveys of the lake. Although no additional adults have been detected in Bone Lake post-treatment, veligers (the juvenile life stage of zebra mussels) have been detected. While only time will tell if the treatment is successful in the long-term, the negative surveys for adult zebra mussels provide hope in the value of systematic surveillance and early detection.

Starry Stonewort detected in Grand Lake

Starry stonewort was initially found by a volunteer citizen scientist as a small population during a 2017 Starry Trek event (MAISRC/UMN Extension program). Following subsequent surveys by the MN DNR, the population was confirmed to be isolated near the public boat launch. Working with local partners, the MN DNR implemented a rapid response effort to hand pull the starry stonewort. After three years, the starry stonewort has not expanded its range within the lake and continues to decrease in abundance annually, suggesting the possibility of eventual elimination. This success was enabled by the early detection effort of trained volunteers.

SECTION I: Components of a Statewide Surveillance and Early Detection System

In this section, we will provide a framework and identify key components of an effective statewide surveillance system.

A statewide surveillance purpose and objectives

A well-defined purpose for a surveillance program is critical for communicating objectives, which can be measured over time to track the program's performance (see *Evaluation* in subsection iv). A statewide surveillance program for AIS should have objectives that clearly describe how the data collected through the surveillance activities will be used considering the infestation status of the AIS of interest and public support[44] of the associated management plans. A few examples of objectives include to monitor the distribution of an AIS over time, to prevent and control spread,[45] for early detection and rapid response.

The purpose of the surveillance program should include information on:

i) the objectives of the surveillance program and the actions that will be triggered by findings,
ii) the target species and geographical area to be surveyed (see subsection),
iii) the methods and strategies to be implemented for each objective/species/geographical area. To ensure active participation and improve confidence in the results, it is important that the purpose and objectives of a surveillance program are co-developed with relevant stakeholders.

Surveys and Inspections

AIS will be introduced and spread to new areas despite even the most robust prevention program. However, the time between the establishment of a species in a region, its subsequent, secondary spread to new locations, and the resulting impact represents a window of opportunity for detection and efficient management. Surveys and monitoring activities generate information on the occurrence and distribution of potential AIS and enable informed management decisions to guide such efforts.

A. Identify flagship species for surveillance

Identifying which species are likely to have significant ecological or socioeconomic impacts is critical for developing effective surveillance and early detection programs, as it guides the detection and response efforts, which go hand in hand. In Minnesota, prohibited invasive species are those with the highest risk to the state's natural resources and economy and could be used as the flagship species. The flagship species of a statewide AIS program can be selected based on their respective pathways of introduction, establishment ability, invasiveness, and life history.

B. Identify priority pathways and locations for surveillance

The large number of waterbodies in the state creates a challenge for effective surveillance and early detection. To better allocate resources and efforts toward the detection and monitoring of AIS, selection of surveillance locations should be informed by an understanding of risk, such that locations or pathways with higher likelihoods of invasion, establishment, damage, and subsequent spread receive greater attention. Pathways of introduction and spread include, but are not limited to, boater movement, organisms in trade, water connectivity, bait release, and pet release. Such prioritization can provide a higher return on investment for surveillance efforts.[2, 21] Decision support tools can provide managers with information about priority locations for surveillance and tradeoffs between alternative surveillance and management objectives. Such tools are discussed in further detail in Section II.

C. Provide direction on surveillance activities

In addition to the identification of priority target species, pathways, and locations, determining the appropriate study design, including justifications, protocols, sampling methods, comparison groups, and questionnaires are all important considerations when planning surveillance activities. Surveillance systems require long-term cooperation and coordination of many individuals. The system adopted must be feasible and acceptable to those who contribute to its success. The system should be sensitive enough to provide the information needed to meet the system's objectives, which minimize the resources necessary for following up on detections.

Protocols, standardized techniques, and guidance on the location, frequency, and intensity of surveillance activities must be developed specifically for each AIS. The use of standardized methods creates consistency in data collection and allows for comparisons across space and time. In addition, the dissemination of surveillance results (positive and negative) should align with the systems' purpose and objectives and be available to all stakeholders.

C.1 Standards

Surveillance standards are a set of guidelines on how to conduct surveillance activities. Surveillance standards tend to fall into one of two categories, input-based or output-based.

Input-based standards

Traditionally, surveillance standards are input-based, aiming to achieve a similar outcome across different agencies or authorities engaged in surveillance activities. For example, sampling strategy, sample size, method, and frequency of survey activities are outlined by the surveillance standard. The advantages of using an input-based approach lie in communication, standardization, and verification. It is generally easier to train new personnel and compare surveillance results across locations or pathways using input-based standards.

Output-based standards

Output-based standards address variability by prescribing what surveillance activities should *achieve* vs. what they should *do*. For example, an output-based standard may require that surveys need to yield a 99% confidence that a waterbody is free of a specified AIS at a specified detection threshold. While guidance is provided on how to achieve the desired outputs, there is flexibility to address differences in the entities being surveyed (e.g., waterbodies, pathways, counties, etc.). Two common approaches to output-based surveillance are based on (1) surveillance sensitivity, or the probability of a positive detection given that a waterbody is infested, and (2) confirmation of invader absence or eradication, i.e., the probability that an entity is free from an AIS given that the survey results are negative. A third approach is risk-based sampling, where the waterbodies and/or the locations within the waterbodies are sampled based on a pre-determined threshold of risk. Risk-based sampling has the ability to increase the efficacy of surveillance because fewer samples are needed to detect an invasion or demonstrate freedom from an invasion.[29]

Estimating Sensitivity

Methods to determine the sensitivity of surveillance activities have been developed for a variety of domains, including aquatic resource management, public health, livestock production, wildlife and biodiversity, and crop production and plant health.[42] For surveillance systems based on active sampling of waterbodies, the detection sensitivity can be estimated based on the sensitivity of both the sampling method (e.g., plot-based methods, such as quadrats sampled along transects vs. plotless methods, such as timed meanders) and the detection method (e.g., artificial substrate samplers).

C.2 Target time periods

It is challenging to determine when a target time period should begin for early detection. When an AIS is first introduced, there may be no signs of its presence. In general, the target time period for detection should start from the moment an AIS is considered detectable using the available detection methods. Inherently, the time to detection is influenced by the life cycle of the AIS, and when within its life cycle, it can be detected. The longer the target time frame, the greater the opportunity for an increase in abundance.

C.3 Sampling design

Surveillance sampling must be designed based on the species, characteristics of the site, population of interest, survey objectives, and desired precision. Due to the complexity underlying each of these aspects, robust analytical approaches, such as eco-epidemiological modeling, are needed to determine how to most effectively and cost-efficiently detect AIS.[28] More information regarding models used for surveillance of AIS and eco-epidemiological modeling is covered in Section II.

Partnerships and Communication

Many entities are currently involved in formal and informal AIS surveillance activities, including local, state, and regional agency staff; lake associations; researchers; and other groups, thus, coordination, information sharing, use of standardized methods, and shared objectives are needed. Considering partnerships and effective communication is critically important, given the current distribution of state funding. Robust partnerships and communication plans that bring together different groups of stakeholders are key for coordinating surveillance efforts, raising awareness of species of concern, engaging more people in AIS identification and reporting, and building trust among stakeholders and the general public. It is important to note that monitoring and surveillance should be coordinated to avoid duplication or gaps in effort and to ensure that sampling is standardized. This will require developing coordination efforts that go beyond communication.

Education, Research, and Training

Education

Education is the systematic process of learning with the goal of acquiring knowledge. Educational activities can be used to increase public awareness of newly introduced, established, or threatening AIS to engage citizens and enhance detection. Such activities may include workshops, fact sheets, videos, identification aids, and public databases for reporting suspect cases.

Training

Training is the process of learning with the goal of performing a skill or behavior. It is essential for professionals and volunteers to be properly trained on topics related to surveillance activities such as sample design, sample methods, identification of AIS, data collection, reporting, and data analysis. The need to train individuals involved in these activities is a continual process that should be prioritized through the life of the surveillance program.

Research

Significant progress has been made in recent years to inform surveillance and early detection programs. However, questions remain, and more research is needed to better understand, monitor, and model aspects of AIS invasions and spread. Scientifically driven surveillance and early detection activities are essential to developing successful surveillance and early detection programs.[46] Below we outline additional research needs in this area:

- Risk assessments (to design risk-based surveillance) *
- Impacts assessments
- Decision support tools*
- Validation of databases that can be used to design activities*
- Assess survey design*
- Incorporation of behavioral data into surveillance methods (species of interest and human behavior)
- Novel detection methods, such as eDNA*
- Economic-tradeoffs*

(*) Active areas of research for the Minnesota Aquatic Invasive Species Research Center

Evaluation

Evaluation of surveillance systems should promote the judicious use of resources by ensuring that appropriate AIS are under surveillance and that those surveillance activities operate efficiently. The evaluation of surveillance programs should include recommendations for improving quality and efficiency, e.g., eliminating unnecessary duplication and incorporating prioritization schemes. Most importantly, an evaluation should assess whether a system is serving a useful function, is meeting the system's objectives, and has stable funding. The evaluation process should qualitatively and/or quantitatively evaluate plans, operations, impacts, and outcomes as defined by the overall objectives and surveillance design.

SECTION II: The use of decision-support tools for resource allocation

Surveillance programs that aim to detect new populations of AIS early enough to control the population before significant environmental or economic damage has occurred are a cornerstone of many management plans.[47] However, the design of effective surveillance programs can be difficult, as they must often overcome challenges in statistical design, large surveillance areas, multiple targets with unknown identity or biology, multiple forms of surveillance data, budget restrictions, and limited capacity. To overcome these challenges, scientists and managers should consider the development and implementation of eco-epidemiological models and decision-support tools that facilitate better-informed decisions regarding resource allocation. In this section, we review recent scientific developments that have led to more informed decision-making regarding surveillance and early detection of AIS around the world. We then focus on the advancements of such tools in Minnesota in the next section.

Ecological niche models (ENM) have been used to predict species distributions based on environmental conditions to guide monitoring and surveillance activities as well as estimate the severity of impact caused by an introduced organism.[48,49] ENM are predicated on niche theory, the concept that species' distributions and abundances are mediated by habitat suitability, or the availability of locations with environmental conditions that are hospitable for a given species.[50] They can be used in conjunction with models that simulate dispersal to understand species' likely futures distributions in order to prioritize monitoring and management interventions.

Traditional ENM have been extended to address the influence of climate change on the prediction of invasive aquatic populations.[49,51] Lee II et al. (2007) developed a general framework for synthesizing information to manage AIS in the face of changing and, at times, volatile environmental conditions. Despite recent advancements in the use of ENM, there are a few caveats. First, biotic and environmental data need to be consistently assessed across scale, resolution, and GIS projection.[52] Secondly, critical data may not be available to predict the probability of occurrence or abundance with the desired resolution to inform management decisions. As with all models, ENMs should be continually updated and validated to assess their accuracy and external validity.[53]

Numerous studies have predicted the occurrence of AIS to support the use of targeted field surveys for monitoring and resource allocation, using non-ENM methods.[54–58] For example, Underwood et al. (2004) used key environmental factors to identify vulnerable regions of invasion in Yosemite National Park. Consistent with similar studies, they found that areas with high levels of human activity and disturbance are more likely to have high levels of invasive species occurrences—likely due to people and their vehicles serving as vectors of spread. Likewise, stream corridors were found to be important pathways of spread due to annual floods that create seasonal connectivity between otherwise isolated riparian habitats.

Risk analysis is a framework for standardizing science-based information to decision makers to prevent and manage invasive species.[60] Risk assessments are key components of risk analyses[61] that determines the likelihood of threats and vulnerabilities and assesses the magnitude of exposures.[60] They can use qualitative or quantitative approaches, or a combination thereof, to estimate the risk of a hazard, or source of potential harm, and have been used in regards to AIS to determine the invasive potential of a plant, invertebrate, fish, or pathogen and to describe the risk of spread for different pathways or vectors.[62,63]

Mechanistic models have been used to predict the spread of AIS, such as the fish species Eurasian ruffe (*Gymnocephalus cernua*), using a variety of methods.[64] Such models are important to inform surveillance both in understanding where to prioritize survey efforts as well as in identifying and quantifying the impact of different mechanisms that contribute to dispersals. Betletsky et al. (2017) investigated the impact of lake currents on the dispersal of Eurasian ruffe and golden mussel (*Limnoperna fortune*) in Lake Superior and Lake Michigan. Their findings supported lake currents as an important dispersal mechanism of golden mussel and identified Green Bay as an optimal location to focus surveillance and control, emphasizing the importance of frequent sampling at high-risk points of introduction.

Resource allocation models integrate ecological and economic information in an optimization framework to assist decision-makers in identifying cost-effective strategies for surveillance and control, explore tradeoffs among management objectives, and understand the ramifications of uncertainty about invasion spread.[65] For example, resource allocation models have been used to identify optimal surveillance and control strategies for environments under continual invasion pressure where the number, size, and location of established populations are unknown prior to detection (5,6). They have also been used to prioritize locations for surveillance effort, given uncertainty about invasion spread.[66]

Current decision support tools applied to AIS in Minnesota

Introduction Risk for Surveillance

Researchers from MAISRC, in collaboration with researchers from the UMN's School of Public Health and College of Veterinary Medicine, have developed an innovative introduction risk model that forecasts the potential risk associated with the spread of zebra mussels and starry stonewort throughout the entire state of Minnesota by taking introduction probability and establishment probability into account. The model estimates the probability that a lake becomes infested by 2025, considering three primary factors:

1. likelihood of AIS introduction due to water connectivity,
2. likelihood of AIS introduction based on boater movement, and
3. environmental suitability. It evaluates approximately 10,000 waterbodies and generates a lake-level risk score (0.0 – 1.0) based on the percentage of times a lake becomes infested out of 10,000 model iterations.

Preliminary research has been done to incorporate hypothetical management scenarios into the model to simulate the mitigation effectiveness of different interventions. This research is ongoing and will predict, for the first time, the benefit (number of infestations averted) and cost (direct management investment) of various prevention activities, compared to the 'status quo' models that are currently in operation.

Optimization for Watercraft Inspection

Decision optimization models are tools that analyze choices in a given scenario and supply end-users with a solution that minimizes or maximizes a performance measure of interest. Such models are ideal for generating transparency in the decision-making process, especially in scenarios in which decisions impact dynamic and complex systems.[65] Watercraft inspection is a primary component of prevention and slow-the-spread programs and are used widely by state and county programs in Minnesota. Watercraft inspections at points of entry to or exit from waterbodies also function as an important component of a surveillance and early detection program by identifying new AIS and associated movements (previous/future waterbodies) and educating boaters on the detection of AIS. Although valuable, the sheer number of recreational boats moving across the landscape, combined with the large number of waterbodies that can be a source or recipient of AIS, make watercraft inspection a particularly difficult program to manage. Researchers at MAISRC, in collaboration with researchers from the USDA Forest Service and the UMN College of Veterinary Medicine, have developed a model that determines the optimal locations for watercraft inspectors that maximizes the number of inspected watercrafts moving from AIS-infested lakes to lakes not known to contain the AIS.[67] The models use the MN DNR's watercraft inspection program database and statistical methods to adjust for bias and gaps to create a complete network of boat movement in Minnesota. The model has been applied to both state and county-level optimizations, accounting for any combination of zebra mussels, starry stonewort, spiny water flea, and Eurasian watermilfoil.

Visualization Tools

The aforementioned risk models for surveillance and the optimization for watercraft inspection locations have been transformed into an interactive dashboard that allows end-users to customize model outputs to fit their needs. This one-of-a-kind dashboard, known as the AIS Explorer (**Figures 3-9**), was publicly released in November 2020. Following its release, eight workshops were held for county-based and MN DNR AIS managers (~80 participants), as well as three webinars for various scientific and public audiences (~750 participants; webinar recordings are available on YouTube and by request). Ongoing support will be available for managers as they use the tool to inform their decisions – their feedback to date has been critical to creating the AIS Explorer. As the underlying models are updated, complexity added, and new decision-support tools created, MAISRC researchers will incorporate those advancements into the AIS Explorer dashboard to ensure it is meeting the needs of state and local managers.

It is important to note that the AIS Explorer should be considered a *support* tool, adding value to existing decision-making processes, not a substitute for these processes. For example, there may be local factors or values not captured in this model that managers should consider when evaluating the model's recommendations.

The AIS Explorer is available at: www.AISexplorer.umn.edu

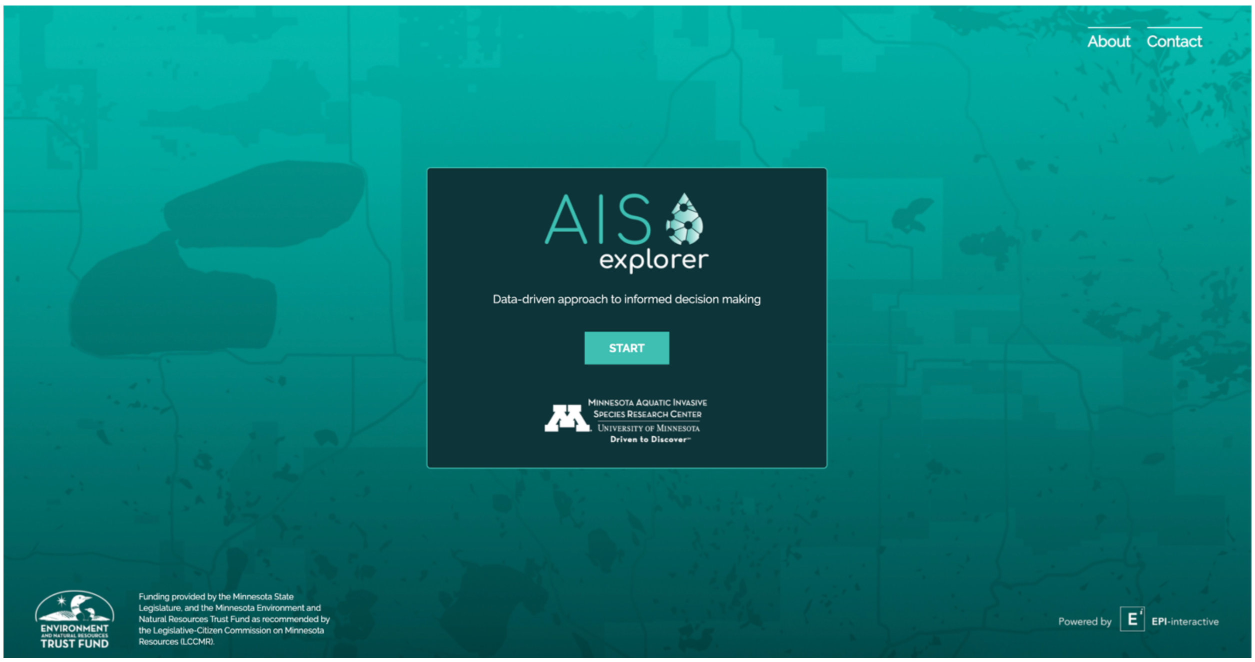

Figure 3. The interactive dashboard welcome page.

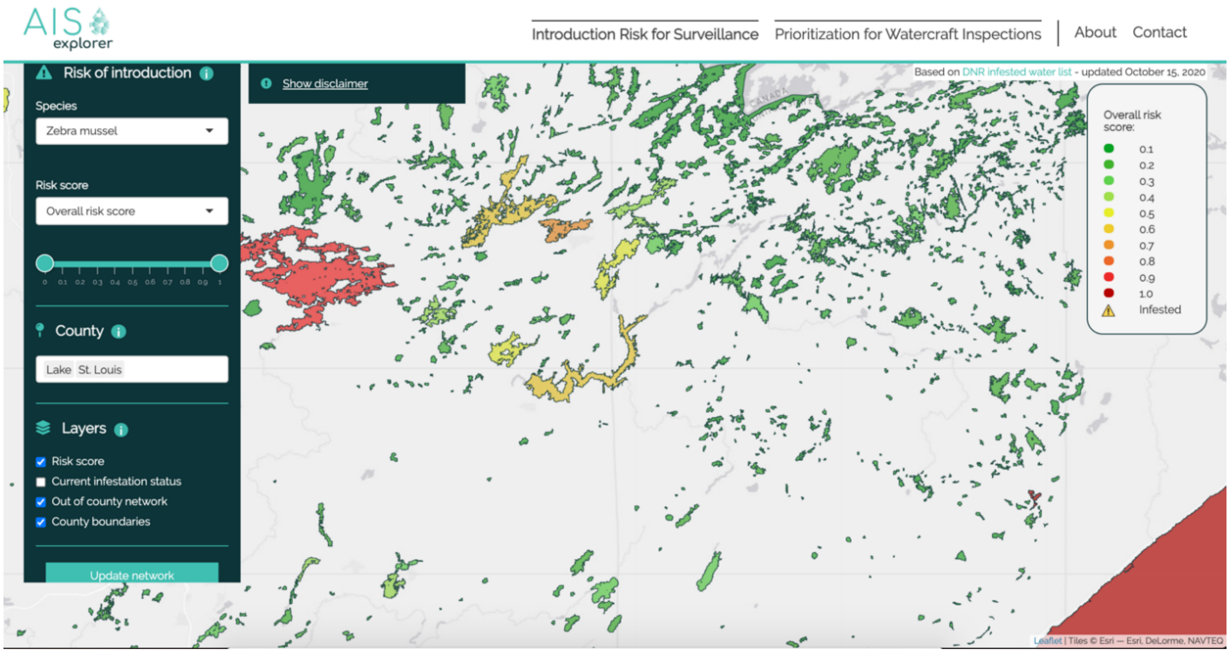

Figure 4. The "Introduction Risk for Surveillance" tab describes a waterbody's risk score or the risk that a waterbody will become infested eight years into the future. The menu on the left-hand side allows the user to tailor the model outputs to their needs, including species of interest and different routes of spread (boater movement or water connectivity). It will also zoom in on the county of interest.

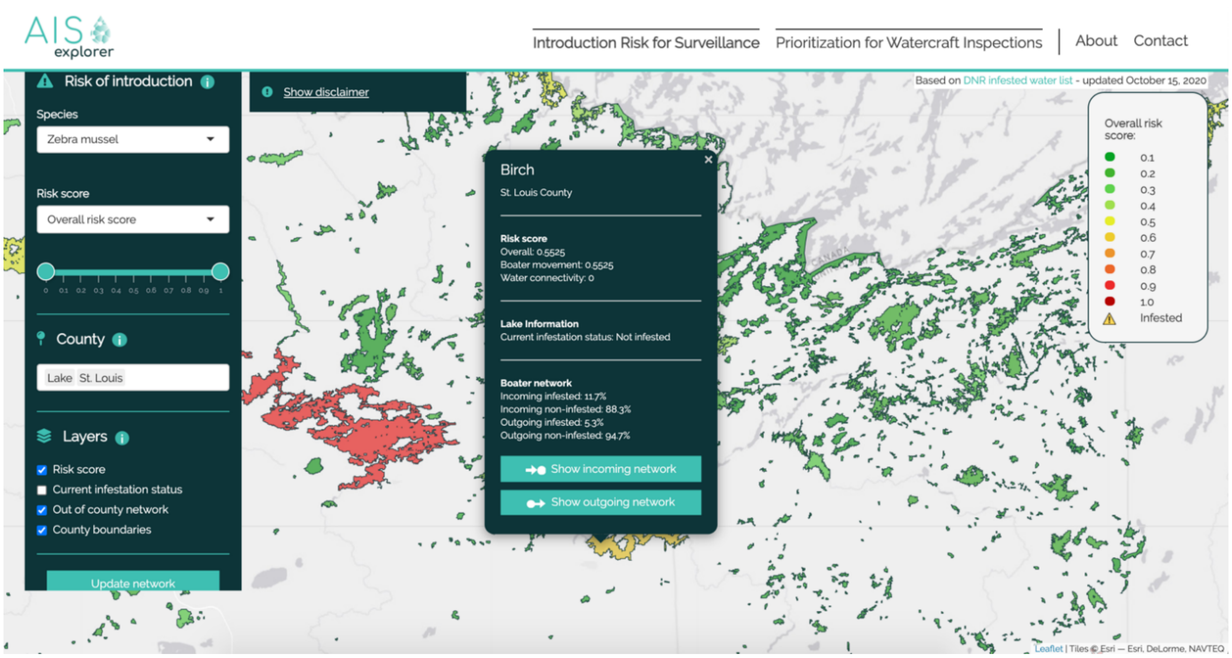

Figure 5. Details of an individual waterbody selected on the interactive dashboard in the "Introduction Risk for Surveillance" tab. In this example we can see that the overall risk score for the selected waterbody and how much of that risk is due to boater movement vs. water connectivity. There is an option below that allows users to visualize the boater movement network constructed of movements directly into and out of the selected waterbody.

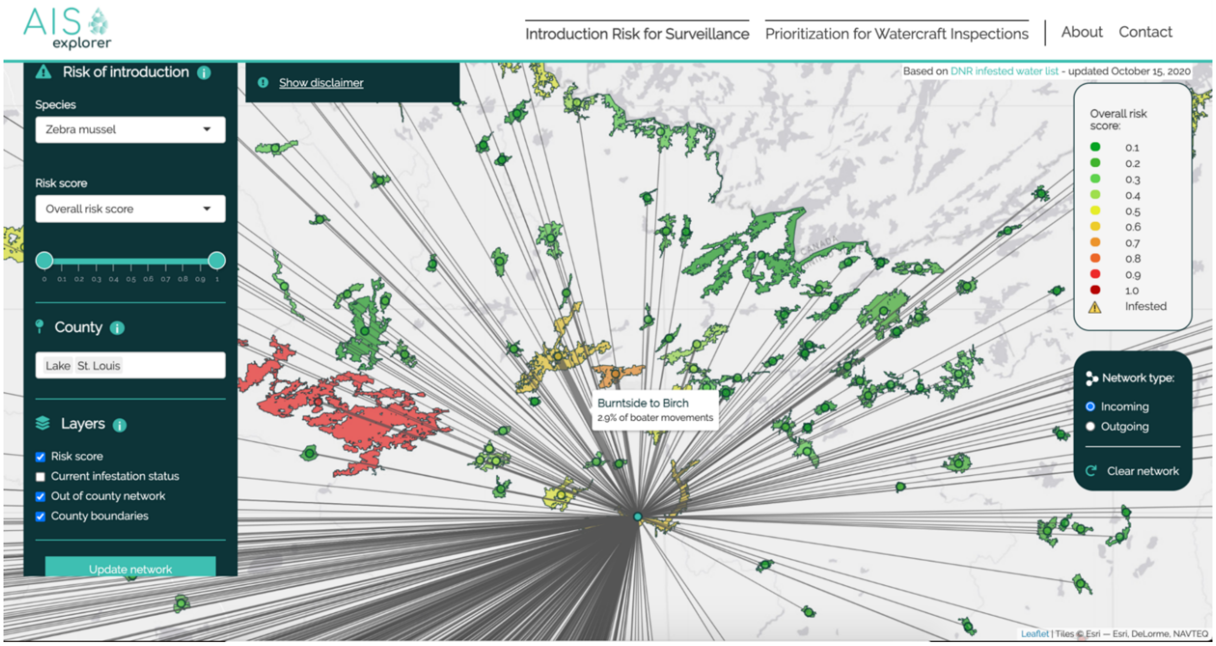

Figure 6. The network of boats heading into the selected waterbody. When the user scrolls over the lines connecting two waterbodies, the percentage of total incoming boat movements is revealed.

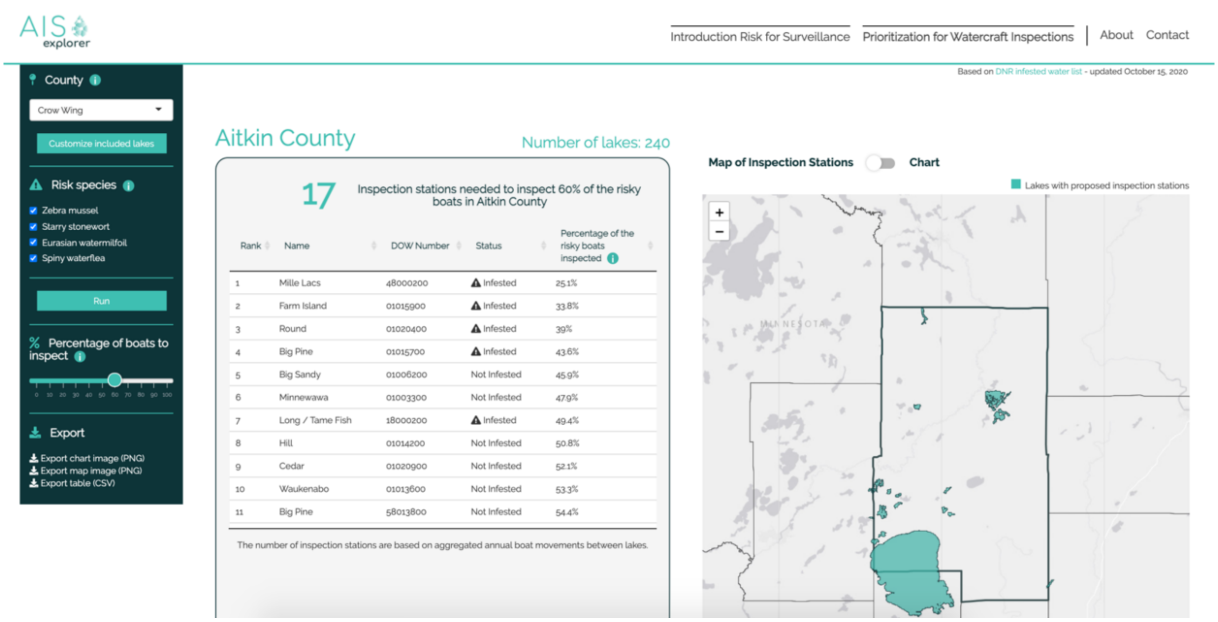

Figure 7. The "Prioritization for Watercraft Inspection" tab showing a list and a map of optimal locations for watercraft inspections and the corresponding map. The menu on the left allows the end-user to select an invasive species of interest, a county of interest, and the proportion of boats to inspect.

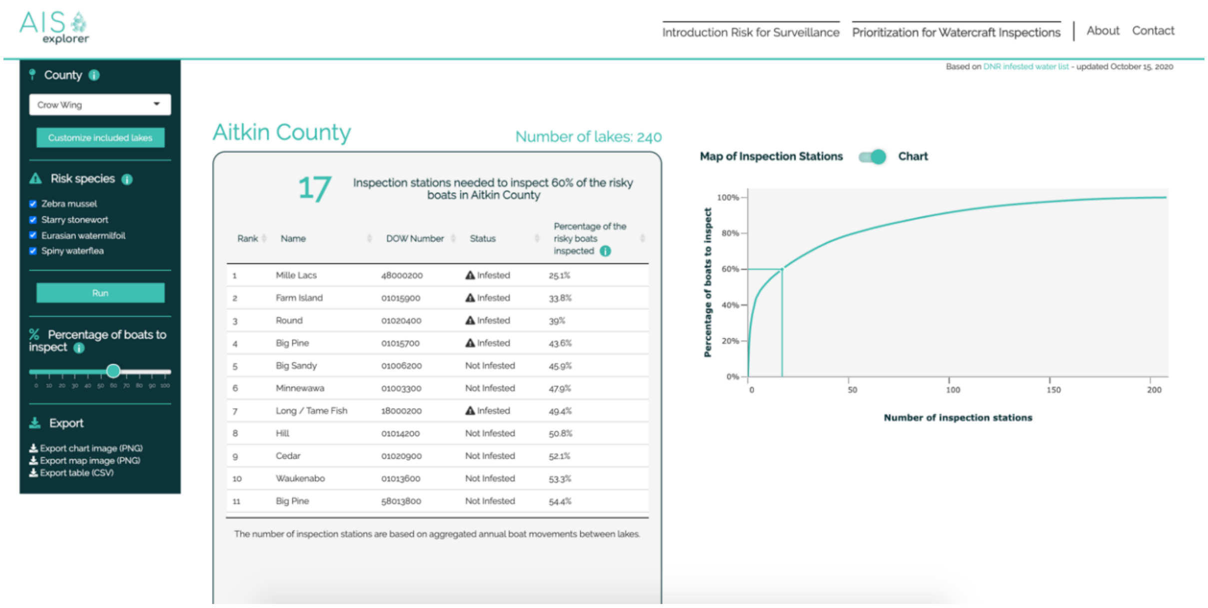

Figure 8. The "Prioritization for Watercraft Inspection" tab describing the optimal location for watercraft inspections and a corresponding chart indicating the point of diminishing returns, where increasing inspection efforts fails to improve prevention outcomes.

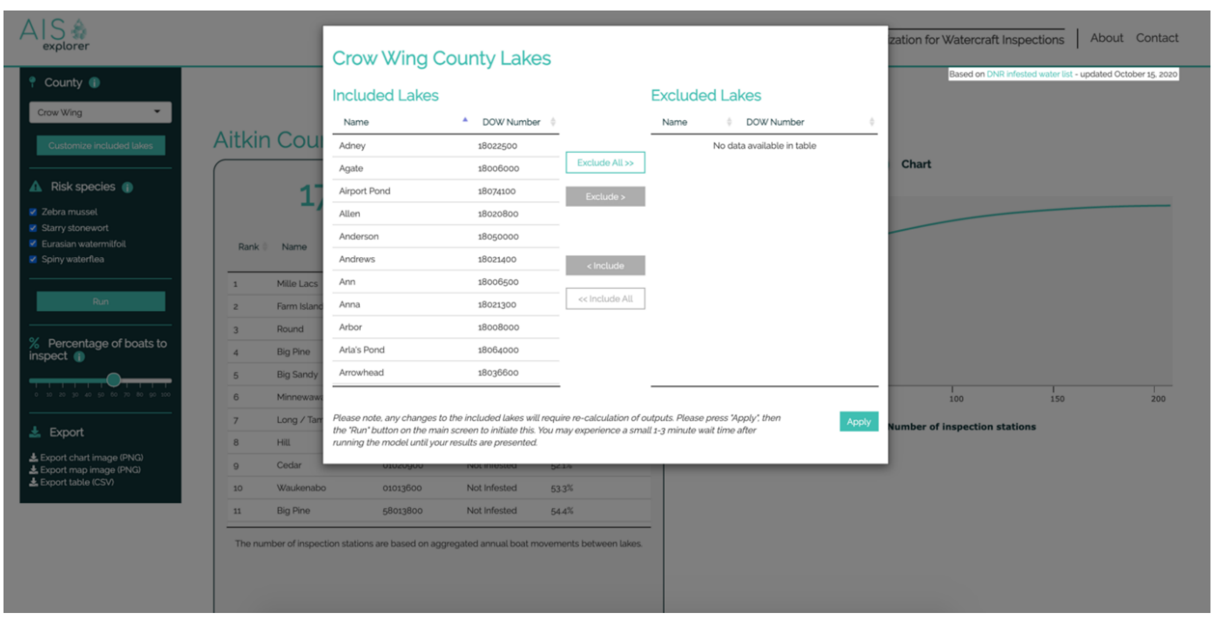

Figure 9. The end-user can manually edit the lakes they want to include to tailor the model to their needs.

SECTION III: Gaps and Opportunities for Existing Surveillance and Early Detection Efforts

Need for statewide surveillance purpose and objectives to guide activities

Surveillance objectives can be developed at different geographical scales (e.g., waterbody, county, watershed, state), which can work in concert to support state-level management goals. Although rapid response plans have been developed at the state and county levels, there are barriers in the development and implementation of surveillance and early detection activities, in particular at the local level. For example, in interviews with AIS county managers we were told that challenges included: available funding, prioritization of resources between surveillance activities and management of existing infestations, lack of motivation due to the widespread distribution of AIS across certain regions, unclear expectations in terms of ability to effectively control new populations, and a smaller labor pool in rural counties. Education on the benefits of surveillance and early detection, guidance on the frequency, intensity, and quality of monitoring to be carried out, and clear communication regarding the specific steps that would occur in response to detecting new populations of AIS is not only essential for motivation and stakeholder buy-in but is also important in designing surveillance activities. Thus, clear definition of the purpose of a statewide surveillance program, with clearly outlined objectives, is critical for gaining support and designing cost-effective and coordinated programs. At the state level, the sensitivity of such surveillance activities must consider the breadth and intensity of the activities at various locations.

Below is an illustration of how activities and objectives can address the purpose of a statewide surveillance and early detection system, using zebra mussels as an example species.

Purpose of statewide surveillance and early detection system: To prevent the introduction and spread of AIS into and within Minnesota	
Species of interest	Zebra mussels (ZM)
Habitat(s)	Dependent on life stage: Benthic, sedentary (adult) Pelagic zooplankton (veliger)
Pathway(s)	Dependent on life stage: Boats, docks, lifts (adult) Natural pathways, water in boats (veliger)
Objective 1	To track the distribution of ZM
Objective 2	Early detection for rapid response in non-infested waterbodies

Activity	**Objectives met**	**Description and notes**
Watercraft inspections	Objective 1	A form of passive surveillance (if locations of watercraft inspectors are strategically placed based on prevention not surveillance); Can be used to identify ZM and other AIS of interest that spread through this pathway; Time frame of detection too long to be used to detect new infestations for rapid response.
Monthly in water near access points	Objective 1 and Objective 2	A form of active surveillance to detect adult/juvenile populations; Since the method of detection identifies adult populations, the time frame of detection it is too long to detect new infestations for rapid response (See Bone Lake example on page 10 for weekly sampling)
eDNA of water samples to find ZM veligers	Objective 1 and Objective 2	A form of active surveillance to detect veligers; depending on sample design the time frame may be suitable for early detection and must consider sampling intensity (frequency and coverage) in conjunction with ZM life cycle.

Table 2. An example of how the purpose and objectives of the surveillance system are connected to surveillance activities using zebra mussels (ZM) as an example.

Variability in effort across spatial scales

Although there have been high levels of engagement and innovation overall among counties, there is variability in surveillance and early detection effort and sampling methods across counties.[68,69] This variability is partially driven by differences in the aid received by each county; but other factors, such as the number of dedicated AIS staff, background and expertise of AIS program managers, and interagency relationships, also influence these efforts. Similar variability exists within state programs, where decisions to develop and implement passive and active surveillance programs is largely led by regional MN DNR staff to meet local management objectives. While there are some benefits to a de-centralized program (e.g., more responsiveness to local stakeholders), it risks falling short of statewide management objectives and may create inefficiencies. Identifying barriers to a more coordinated and cost-effective surveillance and early detection program and creating opportunities to overcome these barriers will be essential to improving outcomes.

Support for innovative multidisciplinary, science-based decision making

Managing AIS is complex, and local government staff responsible for managing county-level AIS activities should receive support in designing surveillance plans. The tools described in this report can be used to increase the efficacy of surveillance activities and reduce redundancy. For example, AIS Explorer's Introduction for Risk Surveillance and Prioritization for Watercraft Inspections can be used to coordinate efforts across scales sharing science-based, state-level information regarding risk to the MN DNR and local-level stakeholders.

SECTION IV: Funding and regulatory implications of a statewide surveillance and early detection program

Overall, Minnesota is well-positioned to develop a statewide surveillance and early detection program that is informed by the expertise and statewide perspective of the MN DNR, makes use of new research and science-based decision support tools, and leverages the local capacity made possible through the AIS Prevention Aid funding. The following recommendations developed in this section were based on review of literature and publicly available government documents, as well as conversations with stakeholders (see acknowledgements list) and experience of the project team.

The AIS Prevention Aid, distributed at the county level, has provided great flexibility to counties that has fostered the spirit of bottom-up, local level innovation, investment in local communities, and created opportunities for technical and leadership skill development in natural resource management at the local level. The program has also brought government closer to the citizens who play a role in AIS prevention and fostered collaboration and cooperation between state and local governments. Therefore, we focus our recommendations on county-level activities, as we see this as the route towards building the most effective statewide surveillance and early detection program. Ensuring proper funding, coordination, collaboration and defining shared management objectives will be imperative to the program's success.

1. Develop a Statewide AIS Surveillance and Early Detection Plan to guide the use of state-aid funding

The Aquatic Invasive Species Prevention Aid provides great flexibility to counties in the use of state-aid funding, stipulating that counties that receive a distribution under this section must use the proceeds solely to prevent the introduction or limit the spread of AIS at all access sites within the county (Minn. Stat. § 477A.19 – 3). Such broad programmatic goals, especially in the case of surveillance and early detection, do not provide sufficient guidance to local governments on how their local decisions can most effectively support regional or statewide objectives. While counties with existing capacity to address AIS have fostered bottom-up innovation and novel partnerships, counties without that capacity have struggled to implement programs to follow the mandate.[69] State and county agencies would benefit from having a comprehensive Statewide AIS Surveillance and Early Detection Plan that allows for local decision-making but can support a coordinated effort to achieve a common goal.

While currently under revision, the Minnesota State Management Plan for Invasive Species identifies goals, desired outcomes, strategies, and actions to prevent, monitor, control, and manage invasive species.[70] This recommended Statewide AIS Surveillance and Early Detection Plan can complement the State Management Plan but will provide more specificity on the purpose and objectives referring to surveillance and early detection and in identifying the role of state, local agencies, and local stakeholders. In addition, the Statewide AIS Surveillance and Early Detection Plan can be updated more readily to adjust to scientific advancements and future invasion scenarios.

This Statewide AIS Surveillance and Early Detection Plan should identify and describe the following items related to surveillance and early detection: purpose, objectives, activity areas, specific actions to undertake for each activity area, leading and cooperating stakeholders and their responsibilities, measurable outcomes, and evaluation. The identification of priorities, the development of specific actions, and the identification of leading and cooperative organizations would help to avoid unnecessary duplication of effort and improve regional coordination.[71] The plan should also include a financial plan that identifies funding sources, trends, and current revenues and identifies costs and strategies for the actions included in the plan.[72] The development of the Statewide AIS Surveillance and Early Detection Plan should involve key AIS partners, including counties and other local stakeholders.[1] The involvement of diverse perspectives helps to ensure that all values and needs are considered in plan development and that leadership and coordination are in place to support the plans.[73]

2. Develop a statewide web-accessible database for AIS efforts

Currently, there is limited centralized information regarding AIS efforts at both statewide and local levels in Minnesota. For example, how many lakes have been surveyed and how were they surveyed?

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[1] DNR Aquatic Invasive Species Partners are the Minnesota Aquatic Invasive Species Research Center (MAISRC), Minnesota Invasive Species Advisory Council (MISAC), Protect your Waters, Minnesota Sea Grant Invasive Species, and Aquatic Invasive Species Advisory Committee. Information retrieved from https://www.dnr.state.mn.us/invasives/ais/programs.html on March 2020.

Which lakes have received watercraft inspection effort and how much effort? Having a comprehensive web-accessible database of surveillance and early detection efforts will facilitate information sharing and set minimum standards for reporting that would, in turn, increase transparency, help develop and maintain public trust, and provide metrics with which the Statewide AIS Surveillance and Early Detection Plan can be evaluated.[71,74] In addition, these data would expand our capacity to develop risk assessment tools and determine the impacts of AIS and AIS management to inform responsive, research-based program development.

A new database and reports must be broadly accessible, easy to use, and exchanged among interested parties routinely. In addition, data obtained from various technologies must be integrated across a range of temporal and geographic scales.[1] In Australia, for example, a database was developed to meet national needs for a central repository of information.[2] The database was one of several key initiatives aimed at providing tools to prevent further introduction of species, facilitate rapid responses to new invasions, and assist with the management of existing introduced species in waters.[71]

Early steps to collect and organize surveillance data are underway, with internal efforts at the MN DNR and various research projects at MAISRC collecting new data or organizing existing, publicly available data. In addition, the MN DNR requests that all counties report their activities related to AIS Prevention Aid funding through a metrics template; however, the reporting is currently voluntary, leading to significant gaps in information availability (**Figure 10**). To make reporting more consistent, the legislature could include standardized reporting of surveillance and early detection activities as a requirement for receipt of state and AIS Prevention Aid funding.

The statewide publicly available database should include activity-level information as well as local and statewide information. In terms of activity-level information, the database should include variables related to surveillance and early detection (such as date of the survey, type of survey conducted, species being monitored, intensity of the survey, weather and site conditions, etc.) and watercraft inspections (such as date and location of inspection, intensity of inspection, violations found and type of violation, actions taken, etc.). In terms of local and statewide information, the database should include general information, such as the number of boats registered by county, type of boat registered, distribution of AIS in the county, and financial information, including revenue sources and expenditures. Further refinement and specific data to be collected would be a component of developing the Statewide AIS Surveillance and Early Detection Plan to ensure it is designed to meet local and state management objectives and provides sufficient stakeholder consultation.

This database could be developed and/or hosted by the MN DNR or the University of Minnesota – both have complimentary database systems and expertise that could be expanded to include surveillance and early detection information. The management plan in Wisconsin, for example, identifies University of Wisconsin–Extension as one of the leading organizations to support data collection efforts.[75] Within the University of Minnesota, two research centers can support these efforts: the Minnesota Aquatic Invasive Species Research Center and the Institute for Urban and Regional Infrastructure Finance.[3] In addition,

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[2] The National Introduced Marine Pest Information System (NIMPIS)

[3] Researchers at IURIF are already collecting data for the Minnesota Transportation Finance Database as part of the Transportation Policy and Economic Competitiveness (TPEC) Program.

these partners can contribute expertise in data visualization to communicate and share findings to inform efforts.[76]

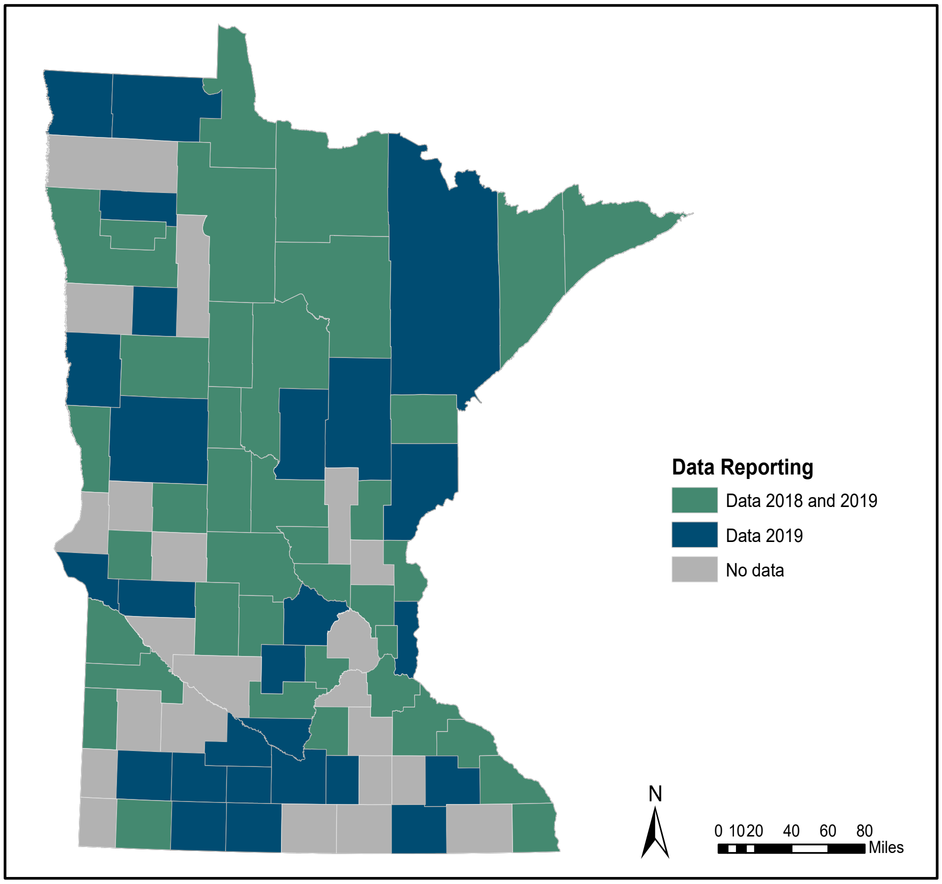

Figure 10. Counties Reporting Metrics to the Department of Natural Resources

3. Increase and/or adjust funding distribution formula for AIS Prevention Aid

Over the last decade, significant investments have been made by the Minnesota legislature, the University of Minnesota, local governments, nonprofits, and many individuals to address the threat and impact of AIS in the state. These efforts dramatically increased public awareness and positioned Minnesota as a leader in the fight against AIS. For example, programs like the Minnesota Aquatic Invasive Species Research Center (est. 2012), new funding via AIS Prevention Aid (2015), and an increase to the AIS surcharge on watercraft registration (2019), have been possible with broad bipartisan and public support. It is important that continued investments and innovation reflect the growing impact and complexity of AIS problems in Minnesota. However, during times of financial stringency, it is particularly prudent to consider efficiencies and coordination to make existing funding most impactful. To that end, and specifically focused on surveillance and early detection, we outline some scenarios for a risk-based allocation of AIS Prevention Aid. We have focused on the AIS Prevention Aid given flexibility in how the funds are spent, interest by county-based mangers involved with the development of this report, and the value of building on local capacity to implement a surveillance and early detection program.

One way to maximize efficiency for risk-based surveillance and early detection is to adjust the funding distribution formula for the AIS Prevention Aid. Minnesota Statutes authorize $10 million a year from the general fund to be appropriated to the commissioner of revenue to make payments (Minn. Stat. § 477A.19 – 5) using the following formula (Minn. Stat. § 477A.19 – 2):

- 50% based on each county's share of watercraft trailer launches, defined as any public access site designated for launching watercraft; and
- 50% based on each county's share of watercraft trailer parking spaces, defined as a parking space designated for a boat trailer at any public water access.

Counties make individual decisions on how funds are used, but resources must be used solely to prevent or limit the spread of non-native aquatic species at water access points within the county (Minn. Stat. § 477A.19 – 3). **Figure 11** illustrates the distribution of 2018 funding across Minnesota counties. The counties of St. Louis and Itasca contain the highest number of watercraft trailer launches and parking spaces and receive the highest level of funding (7.15% and 6.54% of the total funding in 2018, respectively). Counties like Wilkin, Red Lake, Lincoln, and Olmsted receive less than 0.1% of total funding (or less than $9,000). Dodge, Fillmore, Pipestone, and Rock counties do not have public access sites or parking spaces, and, therefore, do not receive funding.

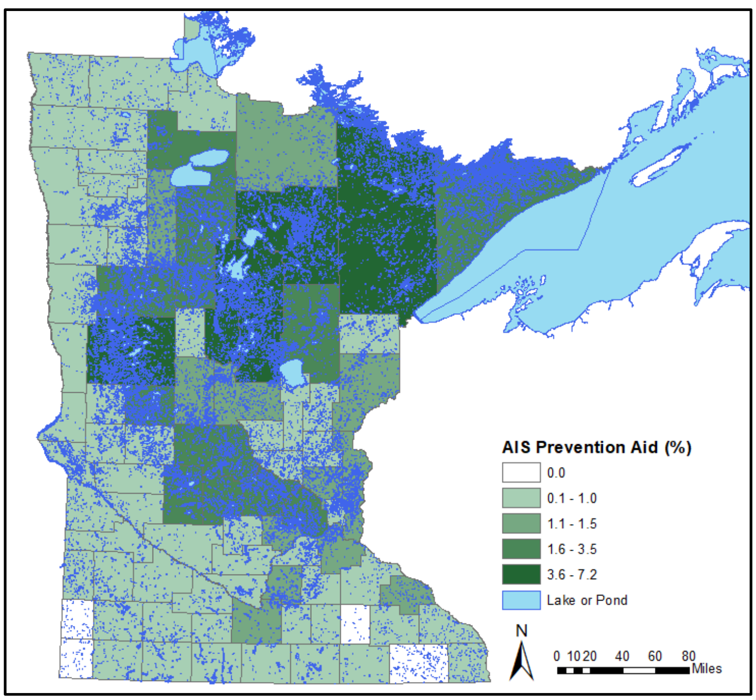

Figure 11. Aquatic Invasive Species Prevention Aid by County (percentage of total funding 2018). *Source: MN Department of Revenue (2018)*

The allocation formula was an excellent and intuitive first step, providing more money to counties with more water access points. However, our research and feedback from local managers suggests that the formula can be refined to account for additional factors that contribute to the spread of AIS. Below we list shortfalls with the existing finding method:

- **Strong correlation between variables used for allocation**
  Public access sites and parking spaces at the public access sites are strongly correlated (see **Figure 12**). The correlation is 0.92 and statistically significant (at the 0.01 level). Therefore, by including both variables the equation increases the concentration of funding amongst counties. Considering more factors that contribute to the spread of AIS, such as distance to infested waterbodies and the severity and type of invasion, counties can decrease funding concentrations to more effectively align resources with AIS risk.

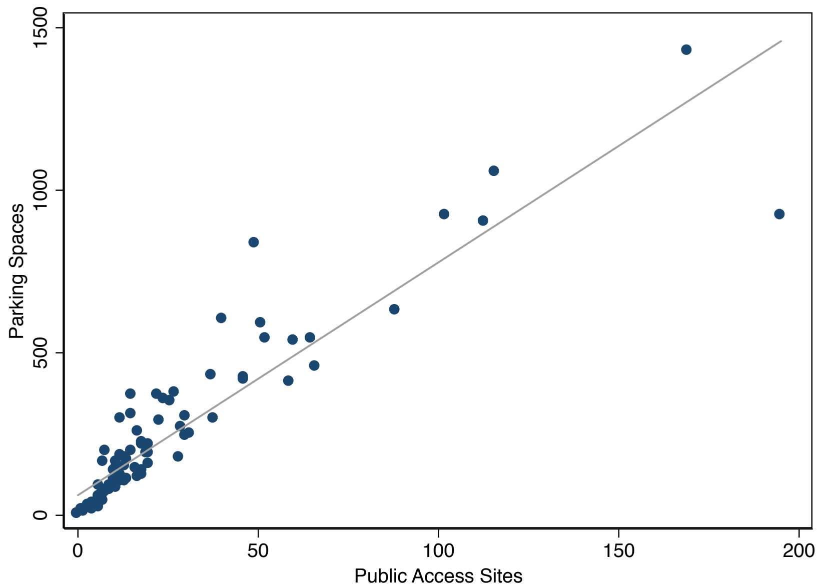

Figure 12. Correlation between Public Access Sites vs Parking Spaces

- **Consideration of only public access points**
  The allocation formula is based on public access points and parking spaces at those points; this method does not consider private access points or the fact that AIS can spread to lakes without boat access. Like many counties, the funding that Lake of the Woods receives does not reflect their needs, given that there are many more private accesses than public access points in the county. The number of private access points is not currently documented but should be considered for future data collection. In addition, through surveys conducted at 22 lakes in 2018 and 2019, a consulting firm found at least one aquatic invasive species in 13 lakes and ponds without boat access in Hennepin County (Fortin Consulting, Inc., 2020). The current allocation creates a disadvantage for counties that have a relatively higher proportion of private water accesses.
- **Adequacy of resources available to counties for AIS prevention**
  Because of the formula, some counties receive a very small portion of resources, which might create additional burdens on them as they undertake projects that cost more than the funds they receive. Counties can save funds from year to year to accomplish larger projects. According to the MN DNR, southeastern counties have reported that the resources they receive to support AIS prevention efforts are not sufficient and sometimes create an additional burden on them.[69] In 2018, seven counties received less than $15,000 in state-aid for AIS prevention (including four with less than $9,000).

The new funding allocation could start from the previous allocation model or be designed as a wholly new allocation method. Given that funding is being distributed to counties, adjusting the existing allocation model could allow for a smoother transition. The following funding allocation is recommendations could be an initial step towards incorporating surveillance and early detection of AIS to better inform risk-based prevention efforts. The formula can be adjusted as AIS surveillance and early detection goals are defined and as more consistent and comparable data are gathered from counties.

This new funding recommendation could allow an opt-out option for counties. Funding of counties that opt out could be used for additional grant funding (see recommendation 4). Counties that do not opt out would assume the responsibility of implementing AIS activities. Counties could self-administer the funds (consistent with the current practice) or, alternatively, follow a delegation agreement approach to reduce the burden imposed on counties that received AIS prevention aid but are not interested in using those funds by delegating all or part of their AIS prevention activities covered by the AIS Prevention Aid to another agency/organization. For example, delegation agreements are currently used by the Minnesota Pollution Control Agency (MPCA) to regulate livestock operation[77] and by the Minnesota Department of Health (MDH) to regulate food, pools, and lodging.[78]

The allocation of resources could include two components. The first component would be a base funding level that sets a minimum amount of funding for all counties to support a baseline level of prevention efforts. The base funding could be, for instance, set to $15,000 or a quarter of one full-time employee,[4] with the encouragement that counties provide cash or in-kind matching support.[5] This base funding would support all counties that receive AIS Prevention Aid funds in their hiring of dedicated AIS coordinators who can prioritize AIS issues in the county and bring together local stakeholders to accomplish local AIS prevention and management goals. Though we acknowledge that, if the current allocation formula is changed, there may be counties that currently have supported staff positions that would no longer be able to.

The second funding component would be allocated based on a formula informed by prevention, surveillance, and early detection activities.

- 80% of total funds based on risk-based prevention activities:
    - 25% Watercraft trailer launches, defined as any public access site designated for launching watercraft
    - 25% Watercraft trailer parking spaces, defined as a parking space designated for a boat trailer at any public water access
    - 30% Watercraft registered in the county (total number of boats)
- 20% of total funding based on risk-based surveillance and early detection priorities

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[4] Several counties have dedicated at least half time of a full-time employee to be in charge of AIS efforts.

[5] The minimum could also be set as a minimum amount of funds per a metric or as a percentage of the proceeds collected from the watercraft registration fee. The feedlot program, for instance, allocates a base funding of $89.98 per feedlot [87]. Similarly, the U.S. DOT adjusts the minimum allocation of federal resources to states to be at least 95 cents for each dollar paid on federal highway taxes by the residents of the state [88].

The funding allocation for a given year would be determined by risk-based prevention, surveillance, and early detection needs. For the risk-based surveillance and early detection component, we recommend that risk is calculated annually based on science-supported, data-driven approaches using eco-epidemiological models, such as AIS Explorer. For example, the cumulative risk, as defined by the AIS Explorer, for each county would provide guidance on the proportional split of the funding. The statewide AIS surveillance and prevention plan would provide guidance to county managers to ensure efficient and effective coordination with a broader strategy. In addition, the implementation of this formula would require a transition period to allow counties to prepare for the adjustment and for models to develop greater capacity to estimate risk for a wider range of AIS. The transition period could be set to three years. In the first year, the funding would be allocated based solely on risk-based prevention. In year two, the counties would transition to 10% of their funding based on risk metrics for surveillance and early detection and 20% in year three.

By reporting metrics that describe surveillance and early detection efforts to the statewide web-accessible database described in Recommendation 2, state and local-stakeholders can better evaluate and coordinate their efforts. These metrics could include person-hours of field surveys and watercraft inspections, as described below.

Person-hours of field surveys conducted

Surveillance and early detection are critical components of a comprehensive prevention strategy, but can be time and financially intensive.[79] Despite interest to do so, without support and/or guidance, some local managers described their hesitation to invest in surveillance and early detection activities. In 2019, 41 counties, out of the 65 reporting, surveyed 531 lakes and rivers for AIS.[80] These efforts included the deployment of 431 zebra mussel settling plates, conducting 380 aquatic plant surveys, and doing zebra mussel veliger tows in 127 water bodies. These surveys reflect effort based on current funding and local priorities, they were not necessarily driven by a statewide strategy or risk evaluation. By developing a statewide purpose and objectives, strategies such as risk-based surveillance could be encouraged and implemented by allocating funds whereby counties with a greater risk of new introductions would receive more money. While this model currently considers only two AIS, zebra mussels and starry stonewort, future work is intended to address additional species.

Person-hours of watercraft inspections

Watercraft inspections are a central component of current statewide and local AIS prevention efforts and serve as a form of surveillance. All MN DNR inspectors and local partners used a standard app to electronically collect inspection information. The MN DNR collects, prepares (fixes or removes incorrect, duplicate, or incomplete data), and analyzes the data. These data are available upon request. The AIS Explorer uses the MN DNR's watercraft inspection program database and statistically adjusts for biases and gaps to create a network of boater movement in Minnesota.

In 2019, 40 counties had an authorized inspection program and performed over 203,599 hours of inspections or 385,480 inspections.[80] The current funding could be allocated to support these efforts in a more strategic way, such as incorporation of watercraft inspection optimization models developed by MAISRC and available on the AIS Explorer (currently at the county level, but ongoing research will expand to include statewide outputs).

New Variable Considered in the Allocation Formula

Watercraft registered in the county

Watercraft registration data can be used to better allocate funds based on risk factors associated with AIS spread. The correlation of this variable with public access sites (0.40) and parking spaces (0.58) are not high, allowing for some variation in the allocation of resources (see **Figure 13**). Consideration of registered watercraft could provide a more strategic funding approach to account for education/outreach, a popular prevention tool by county AIS managers, in the watercraft's 'home county'. This would allow for more sustained impressions/engagement with boaters away from the public access and where interactions would be more efficient and frequent.

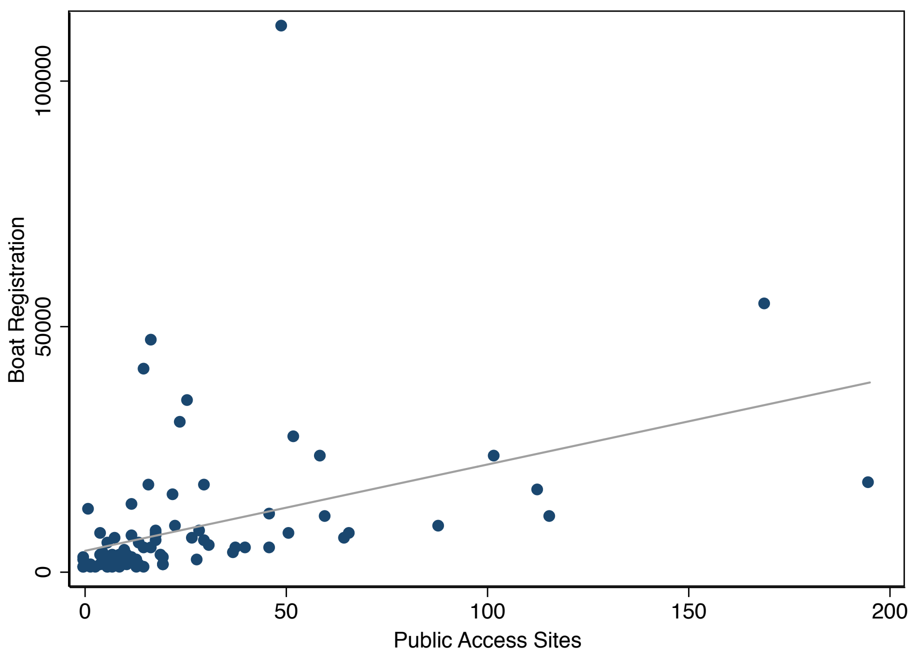

Figure 13. Correlation between Boat Registration and Public Access Sites.

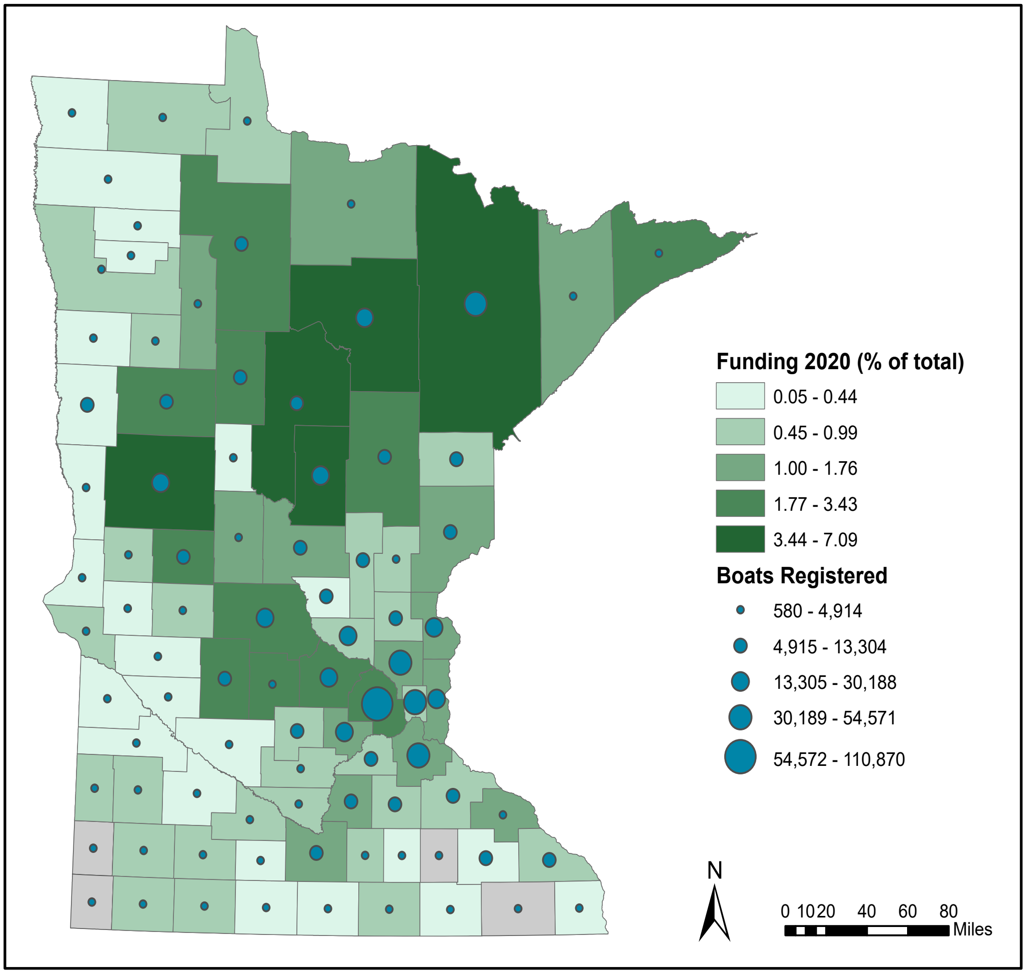

Figure 14. Boat Registration (2019) vs Aquatic Invasive Species Prevention Aid (2020).

4. Strengthen communications to foster regional coordination

AIS issues are often addressed in a "silo," as described by local stakeholders, but coordinated prevention efforts are necessary as water, people, and invasive species move across county and state lines. All stakeholders involved in AIS efforts must recognize that the management of AIS is a shared responsibility, and ineffective or underfunded efforts in one jurisdiction can affect the success of programs in neighboring jurisdictions. Inter-jurisdictional coordination and cooperation may be difficult as there are many stakeholders and priorities around AIS. Developing effective communications could help address those challenges.[81]

The high turnover rate among county staff involved in AIS efforts also affects the flow of communications.[69] Effective communications may help in the onboarding of new staff and development of consistent, shared understanding of strategies. Two key elements were raised in our conversations with local stakeholders that need to be addressed to develop effective communications: having regular communication and having shared access to information. Continuing communication helps to identify gaps and research needs and foster cooperatively working together to correct deficiencies in programs[1]. Regular communications also facilitate the exchange of information about new infestations, plans, actions, and accomplishments. Similarly, having access to the knowledge and skills obtained from past efforts enables informed decision-making, guides and expedites subsequent efforts, stimulates innovation, and reduces costs and time demands, among other benefits.

The DNR has developed passive and active ways to relay information to counties and local stakeholders,[82] which include regional workshops and learning sessions. These meetings provide opportunities for counties and their partners to share and learn from each other's experiences. However, these may only take place once annually per MN DNR region (four regional workshops and learning sessions were reported in the 2018 Annual Report). Information sharing via listservs and websites are also helpful sources of information, although it requires individuals to already be engaged and aware of available information and how to find it.

County AIS partners in Minnesota could benefit from having additional meetings throughout the year, allowing more time to discuss several regional AIS issues and to follow-up more quickly on specific priorities. These can be in-person or virtual meetings to allow for the participation of more counties[6]. Additionally, improved communication between managers and public stakeholders would build trust, streamline information sharing, and facilitate the identification of mutually beneficial priorities.

We suggest an annual statewide meeting to bring together state and local managers, public stakeholders, and researchers. Participants may present the methods or practices they have adopted and discuss benefits and challenges experienced. MAISRC can support this effort, building on their popular AIS Research and Management Showcase to host a second day focused on local management activities with groups such as Minnesota Lakes and Rivers Advocates, the MN DNR, and county partners.

The following are suggested topics to be considered in future meetings. These topics were discussed in conversations with local stakeholders and documents from local governments.

1. Creation of a statewide AIS surveillance and early detection plan
2. Early detection and rapid response strategies[7]
3. Research findings
4. Enforcement strategies
5. Tools to improve the allocation of resources (e.g., watercraft inspections)

It is important to note that the aforementioned need and recommendations to improve communication are only the first steps. There should also be deliberate effort by all AIS stakeholders to coordinate efforts related to surveillance and early detection. While local autonomy can provide benefits (as outlined earlier in this report), ensuring that local and state efforts are coordinated to meet higher-level objectives will improve outcomes. For example, this can include agreeing on a shared purpose, use of standardized methods, or consistent and complete reporting of activities.

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[6] The Annual Report for 2018 reports that local government staff from 39 and 28 counties participated in regional workshops and learning sessions, respectively.

[7] St. Louis County and Waseca County, for instance, include to "*broaden knowledge of and participation in early detection and rapid response activities*" as a main action in their Aquatic Invasive Species Prevention Plan (St. Louis County, 2015; Waseca County, 2019).

5. Strengthen the legal framework for early detection and surveillance, of AIS

Achieving a greater level of regulatory consistency in surveillance and early detection programs benefits natural resources and the public in a number of ways. Statutory definitions serve as key thresholds to our understanding of legislation and may intentionally or unintentionally narrow or widen the lens of meaning.[83] Statutory definitions can help unite diverse legislative audiences. According to Otts (2017), the alignment of state regulatory provisions can increase the effectiveness of the programs; minimize duplication of efforts; and increase awareness, understanding, and compliance. Currently, the definitions for "aquatic invasive species," "surveillance" and "early detection" are not included in the statutes (Minn. Stat. § 84D.01), leading to ambiguity and inconsistency in their definitions. Making the language more explicit could influence prioritization of and resource allocation for these activities.[85] Although rapid response is outside of the scope of this report, we recommend a clearer definition due to its inherent connection to early detection. Therefore, to better support the success of a statewide surveillance and early detection program, we propose the following recommendations to strengthen the legal framework for early detection and rapid response:[8]

Minn. Stat. § 84D Invasive Species

1. Define relevant terms, including but not limited to the following:
    a) <u>Aquatic invasive species</u>: "Non-native plants, animals, and other organisms that have evolved to live primarily in water (aquatic habitats) rather than on land (terrestrial habitats)"[86] that:
        1. cause or may cause economic or environmental harm or harm to human health; or
        2. threaten or may threaten natural resources or the use of natural resources in the state.
    b) <u>Surveillance:</u> "Ongoing, systematic collection, analysis, and interpretation of AIS-related data essential to planning, implementation, and evaluation of practices related to aquatic invasive species"[86]
    c) <u>Early detection</u>: "Identify the presence of aquatic invasive species that pose a risk to landscapes and aquatic areas while they are localized and before they become established and spread to new areas" (U.S. Department of Interior, 2016).
    d) <u>Rapid response</u>: "Swiftly respond to remove any newly detected species while they are localized and before they become established and spread to new areas" (U.S. Department of Interior, 2016).

2. Make explicit "surveillance, early detection, and rapid response" in 84D.02 Invasive Species Management Program for Aquatic Plants and Wild Animals in the following subdivisions:

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[8] A similar approach was proposed by Otts & Nanjappa (2016) for State Watercraft Inspection and Decontamination Programs. According to Otts (2017) Minnesota's aquatic invasive species law and implementing regulations include about 70% of the core authorities suggested in the model legal framework for this matter.

- Establishment (Subd. 1)
- Management plan (Subd. 3)
- Annual report (Subd. 6) - Item 1
  Include detailed information on expenditures for prevention, early detection and rapid response, control and management, restoration, research, education and public awareness, and cooperation[9]
- Contracts for services for emergency invasive species prevention work; commissions to persons employed (Subd. 7)

Minn. Stat. § 477A.19 Aquatic Invasive Species Prevention Aid

1. Update definition of Aquatic invasive species to be more explicit and be consistent with language used in other statutes (update of Minn. Stat. § 84D, see item 1 above).
2. Make explicit "surveillance and early detection" in the use of proceeds (Subd. 3).

[9] Mirroring information of federal funding for invasive species activities (Congressional Research Service, 2018). Categories developed by the National Invasive Species Council to address invasive species (GAO, 2015).

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Glossary

Control- activities that are undertaken to manage the spread of an aquatic invasive species may be biological, chemical, or mechanical

Detection methods- type of equipment used to detect the presence of aquatic invasive species such as settlement plates, field reports, boat inspections, environmental DNA (eDNA)

Early detection- To identify the presence of aquatic invasive species that pose a risk to landscapes and aquatic areas while they are localized and before they become established and spread to new areas

Effectiveness- the ability of a program to produce intended or expected results

Efficiency- ability of the program to produce the intended results with minimum use of time and resources

Eradicate- to extirpate a target population

Established- when an invasive species has spread beyond the place of introduction and become a sustainable population

Invasive species- an organism that is non-indigenous not native to a certain area and is capable of creating economic, environmental, harm or harm to animal or human health

Introduced- species brought to a new location across a natural geographic boundary

Landscape scale- a large spatial scale encompassing a range of ecosystem processes

Risk- the potential realization of undesired consequences or cost of the event based on the probability of infestation occurring in a unit of interest in a specified unit of time and

Risk factor- a characteristic that increases the likelihood of infestation

Risk-based surveillance- the allocation of surveillance activities guided by the probability of an event (introduction or infestation)

Sensitivity- the probability that the surveillance activity is able to correctly detect a new AIS introduction within the target time period

Strata/Stratum- a subgroup of entities used in an analysis

Sample design- how many lakes are chosen at what frequency.

Timeframe- target time frame for detection (e.g., estimated mean lag time for an aquatic invasive species)

Unit of analysis/interest- may be a waterbody, chain of waterbodies, or higher order such as a county or state

Appendix

Current AIS Surveillance and Early Detection Efforts

Numerous activities and programs have been established to combat the spread of AIS at the regional, state, and local levels. While not an all-inclusive list of activities, the information below provides an overview of various programs that are relevant to surveillance and early detection in Minnesota. Existing efforts have been important in slowing the spread of AIS but include many gaps that should be addressed to develop a more robust Statewide AIS Surveillance and Early Detection Plan for the state.

Regional

There are a variety of organizations involved in activities that support the components described in this report. Blue Accounting is a project that collaborates with federal, state, provincial, and private sector organizations. They aim to provide a centralized database of invasive species management activities throughout the Great Lake Basin, including planning, prevention, and monitoring so that the various entities working across this the region are working in a coordinated fashion and have the information they need to evaluate their efforts and progress. Current activities that Blue Accounting is involved with pertaining to surveillance and early detection include the development of a Basin Framework that guides and monitors AIS across the Great Lakes Basin, a species "watch list" and site priority list to inform and target monitoring efforts and outlines methods for monitoring.

The Midwest Invasive Plant Network is an organization that aims to reduce the impact of invasive species in the Midwest. They do so through partnerships with the upper Midwestern states including, Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin, and the Province of Ontario, Canada. Other plant-focused programs include the Great Lakes Hydrilla Collaborative, a platform designed to promote sharing of up-to-date information on prevention and management and includes recommendations on early detection and the Starry Stonewort Collaborative aims to unite experts, managers, and citizens to manage the spread of Starry Stonewort across the Great Lakes Basin.

The Great Lakes Panel on Aquatic Nuisance Species is an organization aimed at multi-jurisdictional coordination and collaboration to enhance AIS prevention and control. The panel is composed of members from the US and Canadian federal agencies, the eight Great Lakes states, and provinces of Ontario and Quebec, regional agencies, local communities, tribal authorities, commercial interest groups, and universities (including MAISRC and Minnesota Sea Grant). Areas of focus include Information/Education, Research Coordination, and Policy Coordination.

Other notable efforts at the regional efforts include EDDMapS Midwest (also known as the Great Lakes Early Detection Network), a multi-stakeholder collaboration that shares data with regard to new invasive sightings. They do this through a website, smartphone or tablet app, and web-based alert system. In addition, the Midwest Invasive Species Information Network is a regional effort to provide resources for early detection and response, which is led by Michigan State University Department of Entomology and supporting partners.

State

University of Minnesota (UMN)

The Minnesota Aquatic Invasive Species Research Center (MAISRC) has led several research projects focused on developing, improving and evaluating surveillance and early detection methods. For example, researchers at MAISRC and collaborators have been working since 2015 to develop epidemiological models to forecast the spread of AIS, estimate environmental suitability of various species and incorporate decision optimization methods to inform resource allocation. These models were publicly released with an online dashboard known as the AIS Explorer (www.aisexplorer.umn.edu). These models continue to be improved with additional data and added complexity. Other research topics of recent/ongoing focus include improved survey design for zebra mussel detection, development of new technologies of eDNA testing and standardized protocols, and statewide risk-based surveys for high-priority AIS, such as hybrid Eurasian watermilfoil and non-native Phragmites.

MAISRC, in partnership with University of Minnesota Extension, has developed two citizen science programs that are focused on AIS surveillance and early detection. The AIS Detectors program aims to empower community members through volunteer programs, events, workshops, and educational offerings to train individuals on aquatic invasive species identifications. These trainings support the development of a statewide network of engaged citizen scientists actively involved with AIS response at the local level. In addition, Starry Trek is a statewide event aimed at early detection of new starry stonewort infestations. This program highlights the importance and value of early detection by trained citizen scientists. In each year, Starry Trek volunteers have found new populations of AIS, including starry stonewort (Hubbard, Beltrami, and Stearns counties), zebra mussels, and golden clams. For Starry Stonewort in Grand Lake (Stearns County), the detection resulted in successful rapid response effort to control a small patch near the public access, highlighting the value of such activities.

Minnesota Department of Natural Resources (MN DNR)

The MN DNR has an Invasive Species Program established by the Legislature to prevent the introduction and spread of invasive species and manage their impacts in Minnesota. Since 1992, the DNR’s watercraft inspection program (WIP) has worked to prevent the spread of invasive species within Minnesota through boater education, in conjunction with watercraft inspection and decontamination at public water accesses. The WIP also serves as a form of passive surveillance, in which they are not actively searching waterbodies for AIS but detections of AIS on outgoing boats have led to the identification of new infestations. Currently, the WIP is operated by one central program manager and four regional supervisors managing approximately 90 DNR watercraft inspectors. Inspectors are placed at public water accesses selected from a tier list developed by the MN DNR. The tier list prioritizes lakes infested with zebra mussels and high levels of boater movement, calculated from the WIP data. The MN DNR also trains local watercraft inspectors authorized by the delegation agreements with the MN DNR resulting in the training of over 900 watercraft inspectors in local government units. The 922 local unit of government watercraft inspectors are deployed based on the goals of each county program administering an inspection program.

In addition to the WIP, the MN DNR participates in additional passive surveillance, such as following up on reports of new AIS sightings made by the general public, including lakeshore property owners. They also engage in active surveillance (actively looking for new infestations,) through a volunteer zebra mussel monitoring program that aims to coordinate citizen efforts in detecting zebra mussels by providing educational materials and a reporting portal. To support the active and passive surveillance programs, MN DNR staff lead trainings for local government, lake associations, and lake consultants on early detection and monitoring of aquatic plants. In addition, the AIS Detectors program and MN DNR have partnered to deliver an aquatic plant identification course for consultants and companies that provide aquatic plant surveys and treatments, lake associations, and the public.

Each year the MN DNR hosts several regional workshops for local government staff that lead the county AIS Prevention Aid programs. The workshops are hosted in different parts of the state and are held to foster collaboration, share information, and keep county level staff current on MN DNR activities and other advance in AIS management.

Statewide advisory and coordinating groups

The Minnesota Invasive Species Advisory Council (MISAC) is a multi-organizational partnership aimed at controlling invasive species (terrestrial and aquatic). The council was formed in response to the Presidential Executive Order 13112 on invasive species, the National Invasive Species Management Plan, and includes representation from a variety of agencies including the Minnesota Department of Agriculture (MDA), the MN DNR, UMN, and local organizations. The purpose of the MISAC is to provide communication and coordination among the member organizations to implement the Minnesota Statewide Invasive Species Management Plan, including science-based early detection.

The Minnesota AIS Advisory Committee advises the MN DNR on its AIS program. The committee was created in 2012 by the MN DNR commissioner to help maintain strong relationships with AIS stakeholders. There are 15 members and five ex-officio members with a wide range of personal and professional experience, including private, non-profit, and public sector organizations actively engaged with AIS issues.

Local

At the local level, counties lead efforts on activities aimed at mitigating AIS introduction and spread, and some of those include surveillance and early detection. We interviewed 16 out of 87 counties that receive ~50% of the annual AIS Prevention Aid. They see the legislative language surrounding the state prevention aid as a way to foster the spirit of bottom-up, local-level innovation. But it leaves county managers with little guidance on surveillance and early detection, leading to a mismatch between intentions and outcomes. For example, counties have prepared rapid response plans for new invasions, even setting aside contingency funds. However, the frequency, intensity, and quality of monitoring carried out often does not result in data that can meet the requirements of a rapid response effort, as most detections are too late to rapidly respond. Furthermore, only a minority of AIS county managers interviewed consider surveillance and early detection to fall in line with the purpose of the funds ("solely to prevent the introduction or limit the spread of aquatic invasive species at all access sites within the county"). As a result, most interviewed county managers choose to prioritize watercraft inspections, decontamination, and education.

General engagement with AIS issues, including surveillance and early detection efforts, have increased dramatically in recent years by lake associations, nonprofits, businesses and individuals. Considerable investments of time and money are made by these local groups to prevent the spread of AIS and mitigate their impacts. Many of these groups have worked closely with local and state managers and MAISRC to become more educated and utilize resources; however, more would need to be done to ensure they are most effectively and efficiently engaged in the collective purpose of a Statewide AIS Surveillance and Early Detection Plan.

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