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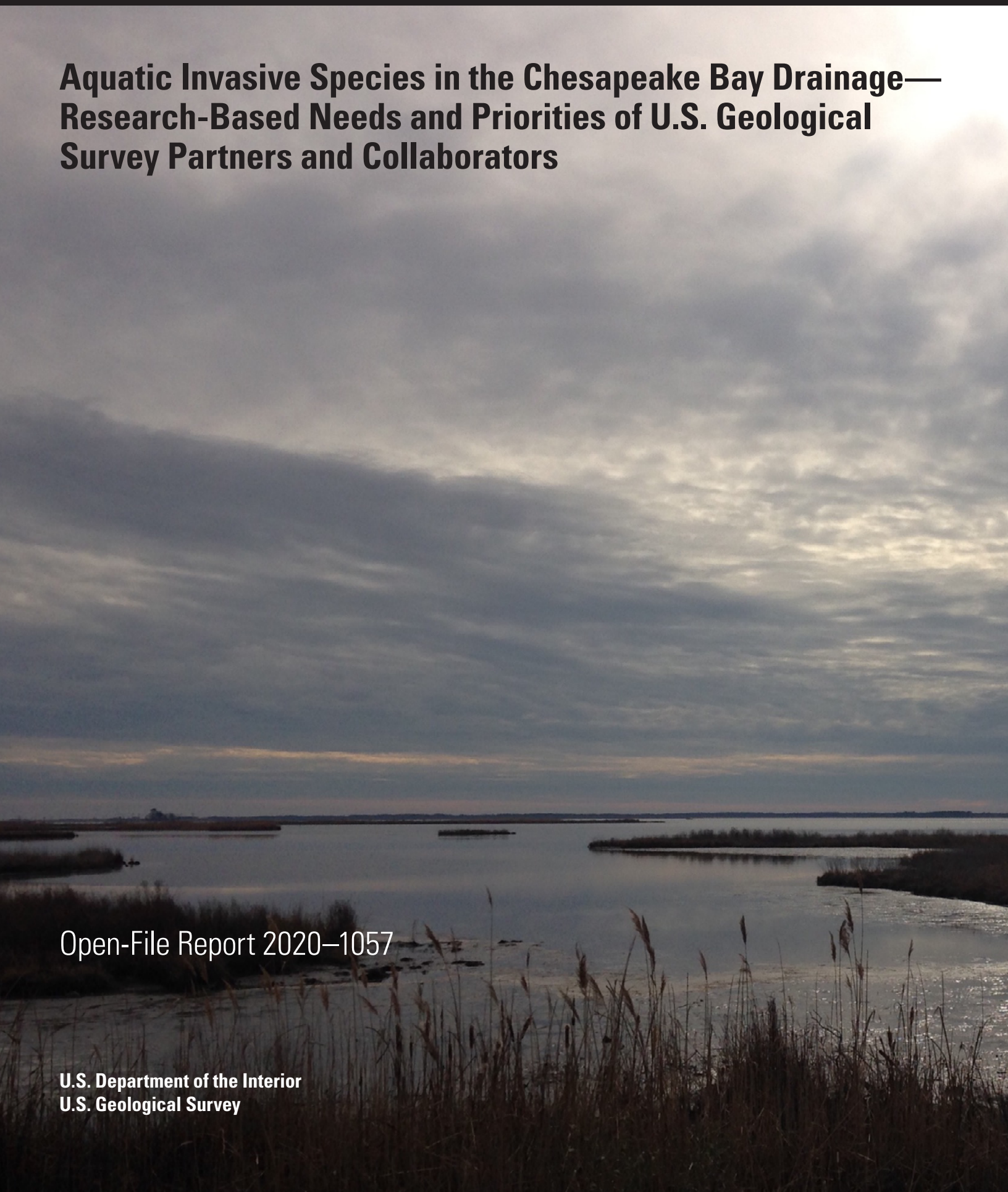
Aquatic Invasive Species in the Chesapeake Bay Drainage—Research-Based Needs and Priorities of U.S. Geological Survey Partners and Collaborators



Open-File Report 2020–1057

U.S. Department of the Interior
U.S. Geological Survey

Cover: Aquatic habitat at Blackwater National Wildlife Refuge (Cambridge, MD), taken January 5, 2015. (photo by Christine Densmore/USGS)

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By Christine L. Densmore

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Thanks go to the U.S. Geological Survey (USGS) staff that coordinates and runs the nonindigenous aquatic species (NAS) database, especially Amy Benson for her guidance and assistance. Members of the USGS team who helped initiate and develop this project include Thomas O'Connell, Andrea Ostroff, Stephen Faulkner, Kay Briggs, and Kelly Maloney. Scott Phillips and Ken Hyer, USGS, provided reviews of this document.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
	Area	

Multiply	By	To obtain
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = (°F – 32) / 1.8.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

ACE	U.S. Army Corps of Engineers
AIS	aquatic invasive species
ANS	aquatic nuisance species
BIA	Bureau of Indian Affairs
BOEM	Bureau of Ocean Energy Management
BOR	Bureau of Reclamation
DC	District of Columbia (Washington, DC)
DCNR	Pennsylvania Department of Conservation and Natural Resources
DEP	(Pennsylvania) Department of Environmental Protection
DGIF	(Virginia) Department of Game and Inland Fisheries
DISC	Delaware Invasive Species Council
DNA	deoxyribonucleic acid
DNR	Department of Natural Resources (MD), or Division of Natural Resources (WV)
DNREC	Delaware Department of Natural Resources and Environmental Control
DOEE	Washington DC Department of Energy and Environment
DOH	(Pennsylvania) Department of Health
DOI	U.S. Department of the Interior
DOT	Department of Transportation
eDNA	environmental DNA
EPA	Environmental Protection Agency
FS	Forest Service (Department of Agriculture)
FWS	Fish and Wildlife Service
FY	fiscal year
GIT	Goal Implementation Team
HUC	hydrologic unit code
ICPRB	Interstate Commission of the Potomac River Basin
ISMT	Invasive Species Matrix Team (Maryland)
MAPAIS	Mid-Atlantic Panel on Aquatic Invasive Species
MSA	Maryland State Archives
NAS	nonindigenous aquatic species
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NY DEC	New York State Department of Environmental Conservation
OPRHP	(New York State) Office of Parks, Recreation, and Historic Preservation

PDA	Pennsylvania Department of Agriculture
PFBC	Pennsylvania Fish and Boat Commission
SRBC	Susquehanna River Basin Commission
USDA	U.S. Department of Agriculture
USDA-APHIS	Department of Agriculture, Animal andPlant Health Inspection Service
USGS	U.S. Geological Survey
VDCR	Virginia Department of Conservation and Recreation
WS	Wildlife Services (within USDA APHIS)
WVDNR	West Virginia Division of Natural Resources
YOY	young of year

Aquatic Invasive Species in the Chesapeake Bay Drainage—Research-Based Needs and Priorities of U.S. Geological Survey Partners and Collaborators

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Executive Summary

The U.S. Geological Survey (USGS) is revising the Chesapeake Bay-based science plan to align it with recent U.S. Department of Interior and USGS science priorities that include, as stated in the plan, providing "an integrated understanding of the factors affecting fish habitat, fish health, and landscape conditions" in Chesapeake Bay and its watershed. A report of partner agencies' needs and priorities related to aquatic invasive species (AIS) science was identified as an informational gap; a report would help to further development of the science program related to aquatic animal health and habitat. This objective was addressed through review of pertinent documentation and conversations with representatives of State, Federal, and regional agencies with vested interests in AIS management in Chesapeake Bay and the Chesapeake Bay drainage area, and this document was produced to summarize the related findings.

All agencies and organizations (13) reported that AIS are of general concern, with most stakeholder groups reporting AIS-related issues to be of high priority, including invasive fishes and invertebrates, invasive plants, and microbes including aquatic animal pathogens.

- **Invasive fishes** are of great concern to all partner agencies. *Channa argus* (northern snakehead) and *Ictalurus furcatus* (blue catfish) are high priority and represent the two most named AIS of concern for these agencies. Nine of 10 stakeholder groups listed northern snakehead as a high priority species, and 6 listed blue catfish as a high priority species as well. *Pylodictis olivaris* (flathead catfish), **invasive crayfish species**, and **dressenid mussels** were also prioritized by multiple partner groups, each receiving specific mention by at least 3 of the 10 stakeholder groups in discussions or documents. Invasive carp, such as *Hypophthalmichthys molatrix* (silver carp), also received mention by multiple agencies (3 of the 10 stakeholder groups) because these fish represent priority AIS in nearby watersheds and a threat for introduction and dissemination within the Chesapeake Bay watershed from these neighboring regions.
- **Invasive plants** are among priority species, and *Hydrilla verticillata* (hydrilla) topped the list. Hydrilla was reported as a priority species by 5 of the stakeholder groups queried. *Trapa natans* and *T. bispinosa* (water chestnut), *Phragmites australis* (common reed), and *Lythrum salicaria* (purple loosestrife) were also among the aquatic invasive plants that were prioritized by multiple partner agencies.
- Multiple stakeholder groups (5 of the 10 groups) also considered *Didymosphenia geminata* **(didymo**) and various **aquatic animal pathogens** among their priority AIS for management considerations.

Science needs that were recurrently indicated by stakeholders to support management of invasive species include

- Technology to enhance biosurveillance capability, such as reliable environmental DNA based detection methodology;
- Risk assessment modeling to forewarn of and prioritize AIS-related threats;
- Increased information and intervention methods related to vectors and pathways of AIS introductions;
- Increased information about the biology and life history of AIS, including information related to trophic interactions, health and disease, and distribution and abundance; and
- Potential applications of mitigation strategies, including genetically based biocontrol mechanisms.

Potential next steps to address the science needs include

- Development of biosurveillance and risk assessment tools for identification of AIS in proactive management;
- Development of proactive management techniques to prevent AIS introductions through recognized vectors and pathways;
- Development of interagency biosurveillance programs to best utilize personnel, funds, and other resources among interested agencies and organizations;
- Investigations to address life history, consequences, and movement/dissemination of top priority invasive species in the region;
- Investigations to determine the potential for novel mitigation technologies, such as the application of synthetic biological (genetic) control methods; and

- Investigations with focus on emerging and high priority AIS in the region, including fishes (blue catfish, flathead catfish, northern snakehead), invertebrates (invasive crayfish and mollusks) and plants (hydrilla, water chestnut, phragmites).

Background

As the largest estuary in the United States, Chesapeake Bay is a vital global resource from ecological and economic perspectives. The Chesapeake Bay watershed includes parts of six mid-Atlantic States plus the District of Columbia in a 64,000-square-mile area that is home to more than 18 million people (Chesapeake Bay Program, 2019) (**Fig. 1**). The estuarine waters of the bay proper and its freshwater tidal and nontidal tributaries are rich in biological resources that support multiple commercial fisheries and provide ecological, aesthetic, and recreational value. Chesapeake Bay has an annual yield of approximately 500 million pounds of seafood, including *Morone saxitilis* (striped bass), *Callinectes sapidus* (blue crab), *Crassostrea virginica* (Eastern oyster), and many other species (Maryland Sea Grant, 2013). Fisheries extend from the tidal tributaries to the non-tidal reaches in many of the 150 major rivers and large streams that feed into the bay. The importance of Chesapeake Bay and its watershed as habitat to native and migratory wildlife is illustrated through its richness in tidal wetlands (more than 280,000 acres), multiple wildlife refugia, more than 50-percent forested land cover, and prominent role along the Atlantic migratory flyway, providing overwintering grounds for nearly a million waterfowl (Chesapeake Bay Program, 2019). The bay and its drainage area are a focal point for recreation and tourism in the region and are popular for fishing and boating as well as terrestrial activities. Efforts to restore and preserve aquatic and terrestrial habitat, including public engagement for bay and bay watershed protection are extensive and arguably quite necessary. Ongoing threats to Chesapeake Bay and watershed health exist from multiple sources, including habitat loss to deforestation and urbanization, chemical contaminant and nutrient loading of water, and aquatic wildlife population declines through overharvesting or disease, among others.

Another prominent biological threat affecting the entire watershed from headwaters to the bay is represented by the influx of aquatic invasive species (AIS). Aquatic invasive species in Chesapeake Bay and its drainage area include animals of multiple taxa, aquatic plants and vegetation, and microbial pathogens. Based on a query of the USGS Nonindigenous Aquatic Species (NAS) program website (https://nas.er.usgs.gov/), the presence of these flora and fauna is not a new phenomenon; reports of aquatic invasive species in Chesapeake Bay and the mid-Atlantic United States date to well over a century ago. Since the latter part of the 20th century, however, increased national and global connectivity through transportation and trade has allowed for enhanced anthropogenically based routes of aquatic species invasion and dissemination in this and other regions. Consequentially, there are now many AIS of concern in Chesapeake Bay and its watershed, and several other species have the potential for establishment in the region (**Fig. 2**). Aquatic invasive species have been and continue to be introduced to the Chesapeake Bay watershed by multiple routes, including transport aboard or affixed to commercial or recreational vessels (ballast water of large maritime commerce ships or biofouling of ship or boat hulls); trade involving live organisms (live bait, aquarium pets, water gardening, live seafood, biological supplier trade); biofouling of gear and supplies used in water activities like boating, fishing, and SCUBA (self-contained underwater breathing apparatus) diving; intentional stocking of aquatic organisms for sport fishing or aquaculture; and natural ingress associated with major changes in waterway connectivity, such as occur with flood events, dam removal, or canal construction

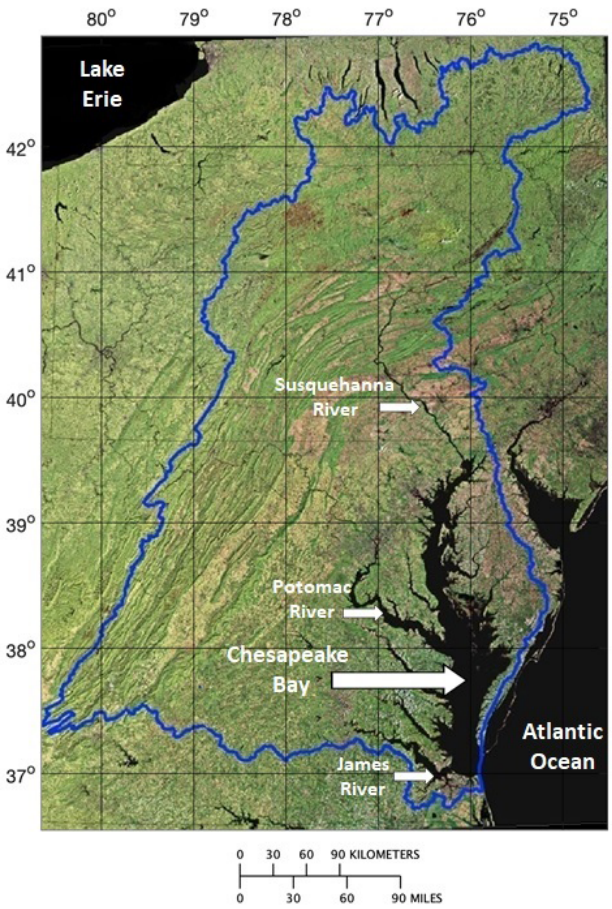

Figure 1. Chesapeake Bay drainage area. The Chesapeake Bay drainage area includes parts of six mid-Atlantic States plus the District of Columbia and covers approximately 64,000 square miles. The blue perimeter line outlines the drainage area, and arrows indicate Chesapeake Bay and the Susquehanna, Potomac, and James Rivers. Image modified from U.S. Geological Survey, https://toxics.usgs.gov/highlights/ChesBay_Report.html

(MD DNR, 2016). Invasive species introductions have been and continue to be either unintentional through inadvertent delivery and escape or deliberate for a variety of purposes. Further dissemination of AIS once introduced may likewise be intentional or unintentional and attributable to the general public, management practices, geographical features, or natural occurrences. By definition, AIS are likely to have negative consequences, ecologically, economically, or in combination, on their new habitat and its native residents. These negative effects often involve valued biotic natural resources, such as commercially and recreationally important fisheries, vegetation supporting beneficial habitat, or aquatic trust species, such as migratory waterfowl, interjurisdictional fish populations, or threatened/endangered species. Economic costs of invasive species in the United States total well more than $100 billion annually (Pimentel and others, 2005). Regions with substantial resources devoted to fisheries and aquatic habitats certainly represent significant components of this economic cost. Invasive fish alone cost the United States $5 billion in 2005 (Pimentel and others, 2005). A 2016 assessment of the cost of AIS to the Great Lakes States resulted in an estimated annual economic cost of more than $100 million (Rosaen and others, 2016). In the mid-Atlantic region and the six States in the Chesapeake Bay watershed, economic consequences of AIS also stand to be substantial. The ongoing highly integrative Chesapeake Bay restoration efforts, as exemplified and defined through the 2014 Chesapeake Bay Watershed Agreement (Chesapeake Executive Council, 2014) and its 10 goals and outcomes, depend in part on the ability to address AIS impacts in the region. While these critical goals and outcomes include maintaining sustainable fisheries, preserving vital habitats, and ensuring good water quality throughout the Bay and its drainage area, fully realizing these and other benefits also depends on the successful prevention and mitigation of AIS related consequences.

The USGS is revising the scientific research efforts for the Chesapeake Bay to align with recent U.S. Department of Interior (DOI) and USGS science priorities and in accordance with four defined science themes (fish habitat and health, coastal habitats and migratory waterbirds, land use and change, science integration and stakeholder information). This revision and description of the thematic areas and associated science planning are outlined in the multi-year workplan (2020–2025) developed in 2019 by the USGS Chesapeake Science Team. The focus of the first of these themes as stated in the science plan is providing "an integrated understanding of the factors affecting fish habitat, fish health, and landscape conditions" in Chesapeake Bay and its watershed. Science needs outlined in Theme 1 include priority issues associated with AIS. In order to better define AIS-related needs and priorities within USGS and on behalf of USGS partners and collaborators in Federal, State, and regional fisheries management, an interactive review of AIS with these partner agencies was conducted. This review, initiated in Federal fiscal year (FY) 2019 and completed in (FY) 2020, consists of the following elements:

Figure 2. The aquatic environment is integral to Chesapeake Bay and its drainage area from ecological, economic, and cultural perspectives. Multiple routes of introduction and dissemination of aquatic invasive species in this region are possible and have been realized, including involvement of boating and commercial or recreational fisheries. Image from U.S. Geological Survey.

1. Determine the needs and priorities of Federal and State partners, as well as other authorities related to AIS science and management in Chesapeake Bay and its drainage area.

2. Develop an understanding of the framework for reporting and communicating AIS-related needs of these partners related to scientific research and management tools.

3. Develop recommendations for next steps and identify potential research opportunities within USGS to meet Chesapeake Bay AIS-related science needs.

The purpose of this report is to summarize the needs and priorites of Federal, State, and other partners concerned about AIS in the Chesapeake Bay drainage area in order to identify the next steps and related research opportunities for USGS scientists. On completion of the review of needs and priorities, described herein, the USGS may better integrate productive and meaningful AIS-based research into the Chesapeake Multi-Year Work Plan and help direct AIS-related Chesapeake Bay science in the USGS during FY2020–FY2025. Although terrestrial invasive species that affect ecosystems of Chesapeake Bay and the watershed are of interest, the initial information gathering effort focuses on AIS.

Methods

Objectives were addressed by USGS staff through review of pertinent documentation and conversations with representatives of agencies with vested interests in invasive species management in Chesapeake Bay and its drainage area. Documents produced by State and Federal partners that pertain at least in part to invasive species science or management were first reviewed with special attention to the mention of AIS-related management priorities and science needs. As a follow up, USGS staff conducted discussions with agency representatives by telephone or by in-person meetings for the purpose of facilitating interagency discussion on aquatic habitat science needs, or as meetings convened for the routine purpose of addressing AIS-related topics. (USGS was an invited guest.) Points of discussion included, but were not limited to, AIS-related needs and priorities, challenges and data gaps in AIS-related science and management, any recent updates or revisions to written documentation and policy, internal and external frameworks for AIS-related management and reporting, and past and current partnerships for AIS science and management. Agency-specific AIS-related documents as well as reports and discussions with agency representatives are listed in **tables 1A and 1B**.

Additional AIS data were analyzed through accessing the USGS Nonindigenous Aquatic Species (NAS) program website at https://nas.er.usgs.gov/. General searches for nonindigenous aquatic species information were performed at the hydrologic unit code 6 (HUC 6) drainage area level for those drainage areas of the Chesapeake Bay, including the James, Lower Chesapeake, Upper Chesapeake, Potomac, Lower Susquehanna, West Branch Susquehanna, and Upper Susquehanna (fig 3). Point maps were used to identify nonindigenous aquatic species, reported as clustered specimen

Table 1A. Interviews and conversations with organizational representatives pertaining to aquatic invasive species science and management needs and priorities.

[DNR, Department of Natural Resources; DC, District of Columbia; DOEE, Department of Energy & Environment; DGIF, Department of Game & Inland Fisheries; DNREC, Department of Natural Resources and Environmental Control; ISMT, Invasive Species Matrix Team; DEP, Department of Environmental Protection; DEC, Department of Environmental Conservation; ICPRB, Interstate Commission on the Potomac River Basin; SRBC, Susquehanna River Basin Commission; FWS, Fish and Wildlife Service; NPS, National Park Service; USDA, United States Department of Agriculture; FS, Forest Service; APHIS, Animal Plant Health Inspection Service; MD DNR, Maryland Department of Natural Resources; DOT, Department of Transportation; NOAA, National Oceanic and Atmospheric Administration; USGS, U.S. Geological Survey]

Name of individual or group	Agency or organization	Date	Meeting format			Other
			Telephone	Group meeting	Written responses	
Joseph Love	Maryland DNR	07/18/2019	X			
Katie Zipfel	West Virginia DNR	07/23/2019	X			
Daniel Ryan, Luke Lyon	DC DOEE	08/06/2019	X			
Ray Fernald	Virginia DGIF	08/13/2019		X		*
Edna Stetzar	Delaware DNREC	08/29/2019		X	X	**
Jay Killian	Maryland DNR ISMT	09/27/2019		X	X	***
Gary Walters	Pennsylvania DEP	10/10/2019	X			
Cathy McGlynn	New York DEC	10/30/2019	X			
Curtis Dalpra	ICPRB	09/30/2019	X			
Matthew Shank	SRBC	09/30/2019	X			
Steve Minkkinen	FWS	10/02/2019	X			
Andrew Landsman	NPS	10/09/2019	X			
Mike Ielmini	USDA-FS	10/29/2019	X			
Lynn Creekmore	USDA - APHIS	10/30/2019	X			

*Virginia DGIF meeting August 13, 2019, included Mike Bednarski, Bob Greenlee, Alan Weaver, Paul B, Jeff T (DGIF), Gina Hunt (MD DNR), and Tom O'Connell (USGS).

**Delaware DNREC meeting August 29, 2019, included John Cargill, Ellen Dicky, Brian Galvez, Katie Kadlubar, Matthew Jones, Alison Rogerson (Delaware DNREC), Anna Smith (DE DOT), AK Leight (NOAA), Thomas O'Connell, Stephen Faulkner (USGS), Gina Hunt (MD DNR).

***MD DNR ISMT meeting included Scott Stranko, Sarah Widman, Mark Lewandowski, Anne Hairston-Strang, Joe Love, Mike Naylor, Julie Bortz, William Harbold.

Table 1B. Documentation reviewed related to aquatic invasive species science and management for State and Federal agencies.

[ANS, Aquatic Nuisance Species; AIS, Aquatic Invasive Species; USDA, United States Department of Agriculture; NPS, National Park Service; NRSS, Natural Resource Stewardship & Science; BRD, Biological Resources Division; NPR, Natural Resource Report; DNREC, Department of Natural Resources and Environmental Control; DNR, Department of Natural Resources; DOEE, Department of Energy & Environment]

Authoring agency or organization	Reference	Year	Type of plan			Additional notes
			ANS management plan	Invasive species plan	Other specified plan	
Virginia Invasive Species Working Group	Virginia Invasive Species Advisory Committee, 2018, Virginia Invasive Species Management Plan: Richmond, Va., Virginia Department of Conservation and Recreation, Natural Heritage Technical Document 18-09, 33 p., plus appendixes.	2018		X		
Virginia Invasive Species Council	Virginia Invasive Species Council, 2005, Virginia Invasive Species Management Plan, Richmond, Virginia Department of Conservation and Recreation Division of Natural Heritage, USA, 84 p.	2005	X			
Maryland DNR Invasive Species Matrix Team	MD DNR (Maryland Department of Natural Resources), 2016, Maryland Aquatic Nuisance Species Management Plan: Annapolis, Maryland, MD DNR, 77p. + appendixes	2016	X			
Delaware DNREC	Delaware Department of Natural Resources and Environmental Control, 2015, 2015-2025 Delaware Wildlife Action Plan: Dover, Delaware, USA.	2015			X	Wildlife Action Plan
WV DNR, WV Invasive Species Working Group, Potomac Highlands Cooperative Weed and Pest Management Area	West Virginia Division of Natural Resources, 2014, West Virginia Invasive Species Strategic Plan and Voluntary Guidelines: Charleston, West Virginia, USA.	2014		X		
Washington DC DOEE	Department of Energy and Environment, Government of the District of Columbia, 2015, District of Columbia Wildlife Action Plan, 2015 Update: Washington, D.C. USA.	2015			X	Wildlife Action Plan
Pennsylvania Invasive Species Council	Rapid Response Plan and Procedures for Responding to Aquatic Invasive Species in Pennsylvania.	2019			X	AIS Rapid Response Plan
Pennsylvania Invasive Species Council	Pennsylvania Invasive Species Council, 2016, Invaders in the Commonwealth; Pennsylvania Invasive Species Management Plan. Harrisburg, Pennsylvania, USA.	2016		X		

Table 1B. Documentation reviewed related to aquatic invasive species science and management for State and Federal agencies.—Continued

[ANS, Aquatic Nuisance Species; AIS, Aquatic Invasive Species; USDA, United States Department of Agriculture; NPS, National Park Service; NRSS, Natural Resource Stewardship & Science; BRD, Biological Resources Division; NPR, Natural Resource Report; DNREC, Department of Natural Resources and Environmental Control; DNR, Department of Natural Resources; DOEE, Department of Energy & Environment]

Authoring agency or organization	Reference	Year	Type of plan			Additional notes
			ANS management plan	Invasive species plan	Other specified plan	
Pennsylvania Invasive Species Council	Commonwealth of Pennsylvania Pennsylvania Invasive Species Council Aquatic Invasive Species Management Plan.	2006	X			
New York Department of Environmental Conservation	New York Department of Environmental Conservation, 2015, New York State Aquatic Invasive Species Management Plan. Albany, New York, USA.	2015	X			
National Park Service	Resnik, J. R., 2018, Biodiversity under Siege, invasive Animals and the National Park Service: A State of the Knowledge Report. Natural Resource Report NPS/NRSS/BRD/NRR—2018/1679: National Park Service, Fort Collins, Colorado.	2018			X	State of the Knowledge Report
U.S. Forest Service, USDA	USDA, 2013, Forest Service National Strategic Framework for Invasive Species Management, FS-1017: USDA, Washington, DC.	2013		X		
Department of Defense	U.S. Department of Defense, 2017, Department of Defense: Invasive Species Challenges and Solutions. Washington, DC.	2017		X		

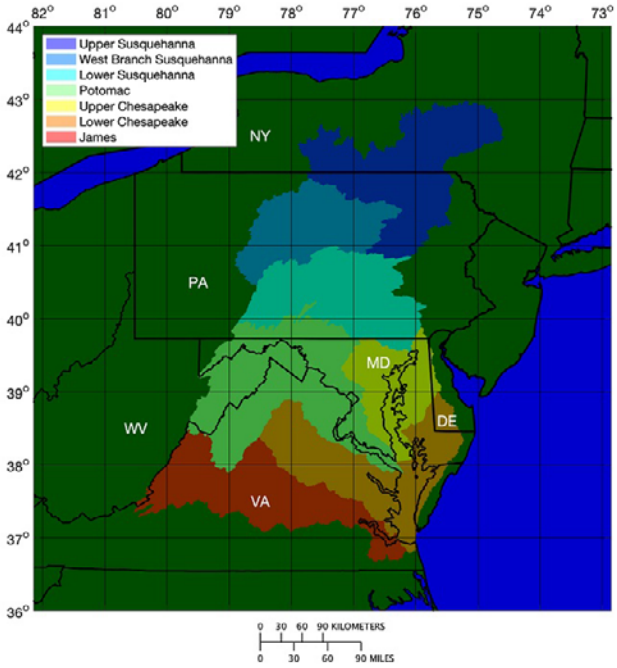

Figure 3. Hydrologic unit code 6 (HUC 6) drainage areas within the Chesapeake Bay watershed includes the James, Lower Chesapeake, Upper Chesapeake, Potomac, Lower Susquehanna, West Branch Susquehanna, and Upper Susquehanna. States in the Chesapeake Bay drainage area are indicated as VA- Virginia, MD – Maryland, DE – Delaware, WV – West Virginia, PA – Pennslvania, NY – New York. Image created by Casey Densmore.

records, in these Chesapeake Bay regional HUC 6 drainage areas. Nonindigenous aquatic species occurrence data were summarized using a spreadsheet for cross-referencing against the information gleaned from interaction with partner agencies and organizations.

Findings

Natural resource management agencies from six states and the District of Columbia, two interstate river basin commissions, and four Federal resource management agencies were consulted via interviews and document review to gather this information. While there are clearly many more agencies and organizations with vested interest in AIS and representing the Federal and State governments, Native American tribes, interstate resources, and conservation interests, the scope of this investigation did not allow for a comprehensive assessment involving all these groups. The agencies and organizations consulted provided a representation of AIS related management issues and priorities throughout the Chesapeake Bay drainage area. Information gathered collectively from discussions with agency representatives and resource documents is summarized in the following section by agency groupings and general subject matter.

Maryland (Department of Natural Resources)

Overview

Almost the entire State of Maryland is within the Chesapeake Bay watershed, except for the westernmost part of Garret County west of the Eastern Continental Divide and the easternmost part of Worcester County along the Atlantic coast. Management of the bay watershed is highly prioritized for Maryland because much of the State's economy and culture are interlinked with the Chesapeake Bay. For the Maryland seafood industry alone, approximately $600 million annually is brought in by a work force of about 4,500 commercial watermen (Maryland State Archives, 2019). Of the 23 counties in Maryland, more than one-half (12) border the Chesapeake Bay proper, and 4 additional counties as well as the large port city of Baltimore border the tidal waters that flow into the Bay.

Management

Aquatic invasive species management within Maryland is achieved primarily through the Maryland Department of Natural Resources (MD DNR) along with other State agencies, including the Maryland Department of Agriculture, Maryland Department of the Environment, and the Maryland Department of Transportation Port Administration. Maryland Sea Grant, a partner of the National Oceanic and Atmospheric Administration and administered by the University of Maryland Center for Environmental Science, is also involved with AIS science for the State. Maryland's AIS-related issues are addressed largely through partnerships among these organizations and spearheaded by the Maryland Department of Natural Resources Invasive Species Matrix Team (ISMT). The 2016 Maryland Aquatic Nuisance Species Management Plan (table 1B) prepared by the ISMT with input from the other agencies is an example of this partnership. Maryland also frequently partners with Federal agencies, including Fish and Wildlife Service (FWS), USGS, the Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), and U.S. Army Corps of Engineers (ACE), on aquatic invasive species issues in Chesapeake Bay and the region. Maryland is well represented for a broad spectrum of AIS-related concerns through participation on the Aquatic Nuisance Species (ANS) Task Force (Federal and ex officio membership) and its regional subgroup, the mid-Atlantic Panel for Aquatic Invasive Species (separate membership). Partnerships for AIS science and management are recognized by the MD DNR ISMT as crucial to furthering the goals set forth by the group in the 2016 ANS management plan, and continued efforts to build

these relationships for addressing AIS issues, and thereby build momentum for the management plan, are of considerable importance to the organization.

Invasive Species

Among the AIS in freshwater currently of greatest concern to MD DNR ISMT are fish, *Ictalurus furca*tus (blue catfish), *Channa argus* (northern snakehead), and *Pylodictis olivaris* (flathead catfish), most notably (**Fig. 4**); mollusks such as *Dreissena polymorpha* (zebra mussel); and plants such as *Hydrilla verticillata* (hydrilla). The 2016 Maryland Aquatic Nuisance Species Management Plan includes lists of (1) "high priority species" already known to be established in Maryland with high a probability of negative consequences and (2) "red alert species" that are not yet known to be established in Maryland but have a high potential for introduction and a high probability of negative impacts. The high priority lists for freshwater animals, plants, and pathogens include

- Species of greatest concern: Fish (blue catfish, northern snakehead, and flathead catfish, most notably), mollusks such as the zebra mussel, and plants (hydrilla);
- Additional priority species: *Faxonius (Oronectes) virilis* (virile crayfish), *F. rusticus* (rusty crayfish), *Procambarus clarkii* (red swamp crayfish), *Myocaster coypus* (nutria), *Cygnus olor* (mute swan), *Egeria densa* (Brazilian elodea), *Iris pseudacorus* (yellow iris), *Lythum salicaria* (purple loosestrife), *Murdannia keisak* (marsh dayflower), *Myriophyllum aquaticum* (parrot feather), *M.. spicatum* (Eurasian milfoil), *Phragmites australis* (common reed), *Trapa natans* (water chestnut), *Didymosphenia geminata* **(**didymo), and *Myxobolus cerebralis* (agent of whirling disease);
- Red alert freshwater species lists include *Hypophthalmichthys molitrix* (silver carp), *H. nobilis* (bighead carp), *Monopterus albus* (Asian swamp eel), *Neogobius melanostomus* (round goby), *Potamopyrgus antipodarum* (New Zealand mud snail), *Aldrovanda vesiculosa* (waterwheel), *Eichhornia crassipes* (common water hyacinth), *Glyceria maxima* (English water grass), *Hydrocharis morsus-ranae* (European frog-bit), *Hygrophila polysperma* (East Indian hygrophilia), *Nymphoides peltata* (yellow floating heart), and *Salvinia molesta* (giant salvinia).

Science Needs

Early warning and early detection related technology, such as methods based on environmental DNA (eDNA), are identified as science related priorities by the Maryland's ISMT. Enhanced understanding of the life history of AIS and the related potential for establishment and dissemination are currently (2020) among the priority AIS-related science needs and science direction in MD DNR. Additional focal topics of interest for the ISMT involve preventive measures and proactive management techniques, such as utilization of risk assessment modeling and vector/pathway identification and interruption practices. Aquatic invasive species pathways of introduction are identified by the ISMT as particularly important areas in need of focus for potential State and Federal partnerships because the topic is largely interjurisdictional and crucial to proactive management of AIS introductions and dissemination. The live trade vector, including pet, bait, and seafood industries, were further identified as a high priority for focus in AIS pathway management.

Virginia (Department of Game and Inland Fisheries)

Overview

Roughly 60 percent of the Commonwealth of Virginia is within the Chesapeake Bay watershed, with water flowing to the bay through four large rivers (Potomac, Rappahannock, York, and James) or along the 7,200 miles of tidal shoreline (VDCR, 2019). Three of the six HUC 6 drainage areas that compose the Chesapeake watershed (James, Lower Chesapeake, and Potomac) are all or partially in Virginia. Because the Chesapeake Bay and its drainage area directly affect a large part of the Commonwealth, AIS are of considerable ecological and economic importance. As such, based on dicussions with DGIF representatives, AIS was identified as one of the most significant management challenges facing resource managers in Virginia.

Invasive Species and Management

The 2018 Virginia Invasive Species Management Plan (table 1B) addresses AIS specifically and includes tables listing AIS of animals, plants, and pathogens managed or monitored in Virginia. Animals and plants mentioned in the plan are

- Fish: northern snakehead, *Mylopharyngodon piceus* (black carp), blue catfish;
- Mollusks: dressenid mussels, New Zealand mudsnail, *Rapana venosa* (rapa whelk), *Corbicula fluminea* (Asian clam);
- Crayfishes: rusty crayfish, *Procambarus virginialis* (marbled crayfish);
- Aquatic plants: water chestnut, purple loosestrife, phragmites, giant salvinia; fig. 5); and
- Other: nutria, mute swan, *Haplosporidium nelsoni* (agent of multinucleated sphere unknown or MSX disease in oysters), and West Nile virus.

A meeting with Virginia Department of Game and Inland Fisheries (DGIF) officials further confirmed that

- Blue catfish, northern snakehead, and water chestnut are among the top priority AIS for the agency, and
- *Trapa bispinosa*, a new species of water chestnut, has emerged in the Virginia parts of the Potomac River watershed in recent years, and its characterization and eradication are of importance.

In the Commonwealth, the Department of Conservation and Recreation (VDCR) and the Department of Transportation each have a role in invasive species management related particularly to parks, natural preserve areas, and transportation infrastructure. The Virginia Marine Resources Commission also has a substantial role related to AIS management in the marine and estuarine waters of the Commonwealth. Virginia DGIF collaborates with Federal and State partners (FWS, USGS, MD DNR, for example) to address AIS; Virginia also has representation on the mid-Atlantic panel for AIS. These types of partnerships are particularly important to the Commonwealth as the need for resources, both personnel and allocated funding, devoted to AIS management is identified as one of the challenges facing the program. Another identified challenge is the availability of tools for detecting AIS in water bodies and monitoring for their presence. A third challenge is related to management decisions at the interface of public awareness and engagement with AIS issues; the risk/benefit of promoting a fishery for a recognized nuisance species like northern snakehead is a relevant example of this challenge.

Science Needs

Environmental DNA technology development and institution of biosurveillance programs were identified science needs related to AIS. Another science need identified by DGIF representatives is the evaluation of the potential for use of synthetic biological control mechanisms through genetic manipulation for AIS applications.

Delaware (Department of Natural Resources and Environmental Control)

Overview

Although much of Delaware is within the drainage areas of the Atlantic Ocean basin or the Delaware River/Delaware Bay watershed, approximately 28 percent of the State (700 of its 2,489 square miles) is within the Chesapeake Bay watershed. Many of the eastern headwaters of Chesapeake Bay originate in Delaware and flow through 15 creek or riverine watersheds into four major rivers (Sassafrass, Choptank, Nanticoke, and Pocomoke) to the Bay (Chesapeake Bay Program, 2018).

Management

Delaware's Department of Natural Resources and Environmental Control (DNREC) has the primary responsibility within the State to manage AIS, with interagency coordination involving the Delaware Invasive Species Council (DISC) and the Delaware Department of Agriculture. Delaware Sea Grant (University of Delaware) coordinates with DISC on issues related to AIS in the State. The Delaware Wildlife Action Plan (2015–25) addresses invasive species issues in Delaware, including aquatic wildlife and aquatic plants.

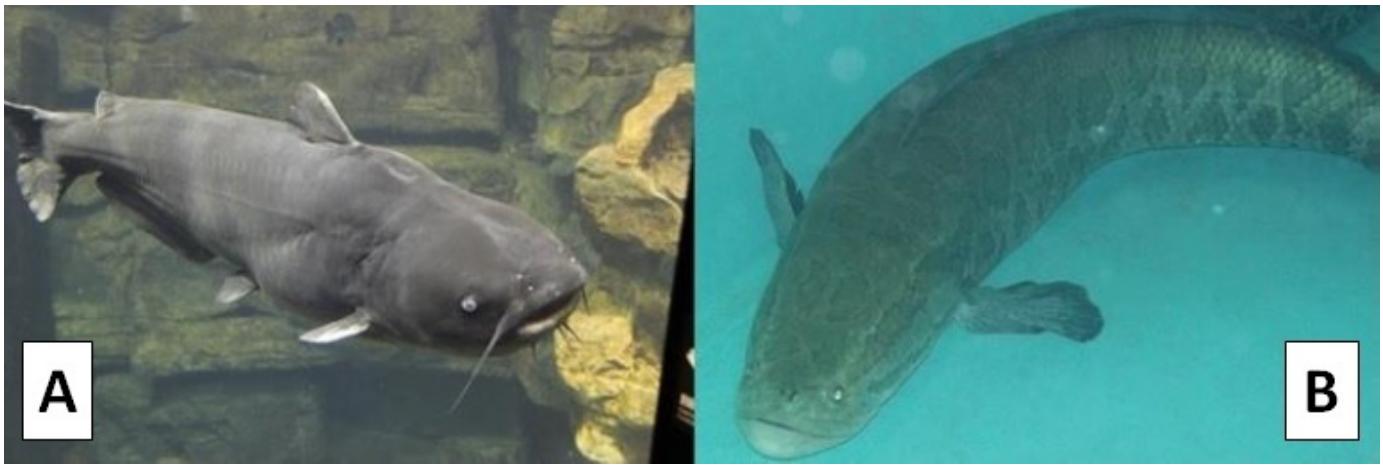

Figure 4. Invasive fish: *A, Ictalurus furcatus* (blue catfish) and *B, Channa argus* (northern snakehead) are top priority invasive fishes identified by Federal and State collaborators of U.S. Geological Survey in the Chesapeake Bay drainage area, particularly among those States adjacent to, or with large tributaries draining into, the bay proper. Images from https://nas.er.usgs.gov/XIMAGESERVERX/2016/20161017153258.JPG (A) and U.S. Geological Survey (B).

Development of an AIS plan is in the planning stages through the coordination of DNREC, DISC, and Delaware Sea Grant. The DNREC Division of Fish and Wildlife also has a northern snakehead management plan in place specific to the effects of this species in Delaware waters. Partnerships for AIS management in the Chesapeake drainage area include other State and Federal agencies such as USDA, FWS, USGS, Maryland DNR, and Virginia DGIF. Delaware participates with these partners as members of interjurisdictional working groups for species-specific AIS management of northern snakehead, invasive catfish, nutria, and the phragmites reed. Delaware also maintains representation on the mid-Atlantic Panel for Aquatic Invasive Species and coordinates and reports AIS management efforts interjurisdictionally through this organization. The most pressing AIS management-related needs for Delaware include development of a dedicated staff for AIS management to direct and coordinate efforts within Delaware agencies and with external partners for management and science, enhanced public awareness and outreach campaigns specific to Delaware AIS issues, and enhanced regulatory authority.

Invasive Species

The Division of Fish and Wildlife of DNREC maintains an AIS website for outreach: https://dnrec.alpha.delaware.gov/fish-wildlife/fishing/invasive-species/. Species listed include

- Fish, such as northern snakehead, flathead catfish, and blue catfish;
- Red swamp crayfish; and
- Aquatic plants, such as *Ludwigia* sp. (creeping primrose), water hyacinth, hydrilla, parrot-feather, and purple loosestrife.

Many of these animal and plant species also receive mention in Delaware's 2015 Wildlife Action Plan (table 1B).

Science Needs

Science-related needs and priorities include risk assessments for predictive and proactive response, with assessments of the potential ecological and economic consequences of AIS. Methods for integration of control and eradication efforts for AIS with restoration programs for other species are also needed.

West Virginia (Division of Natural Resources)

Overview

West Virginia makes up a substantial part of the Potomac River drainage area. There are eight eastern West Virginia counties representing approximately 14 percent of the State's total area within the Potomac River drainage area and hence the Chesapeake Bay watershed (U.S. Department of Agriculture Natural Resources Conservation Service West Virginia, 2019).

Management

Although AIS interests within West Virginia are heavily focused upon invasive carp and other species of concern in the Ohio River drainage area to the west, AIS in the Chesapeake drainage area also are of concern to West Virginia Division of Natural Resources (WV DNR) and other State agencies with invasive species management authority. The West Virginia Department of Agriculture (the only West Virginia agency

Figure 5. Invasive aquatic plants *A, Hydrilla verticillata* (hydrilla) and *B, Trapa natans* (water chestnut) have been identified by stakeholder groups in the region as top priority invasive aquatic plant species in the Chesapeake Bay drainage area. Another species of water chestnut, *Trapa bispinosa,* has recently been identified by Virginia Department of Game and Inland Fisheries as an emerging problem and a high priority for further attention in the Potomac River region. Images from https://nas.er.usgs.gov/XIMAGESERVERX/2015/20151203132214.JPG (A) and https://nas.er.usgs.gov/XIMAGESERVERX/2012/20120424152229.jpg (B).

with legislative mandate to control invasive species), as well as the WV Department of Environmental Protection and the West Virginia Division of Highways, share in general invasive species management interests, but AIS management is led by WV DNR within the State. The West Virginia invasive species management program is outlined in the document, "West Virginia Invasive Species Strategic Plan and Voluntary Guidelines," co-published in 2014 by WV DNR and other interagency working groups (West Virginia Invasive Species Working Group and the Potomac Highlands Cooperative Weed and Pest Management Area). Regionally, West Virginia is represented on the mid-Atlantic Panel on Aquatic Invasive Species, and West Virginia is planning to work with the ANS Task Force on the development of a WV AIS specific management plan by WV DNR.

Invasive Species

Aquatic invasive species related priorities within West Virginia apply largely to the Ohio River Basin, with carp and hydrilla topping the list; however, there is definite interest in AIS and the potential introduction of nonindigenous aquatic species within the Chesapeake watershed in West Virginia. Northern snakehead as an invasive species along the Potomac River and its tributaries is of major concern for WV DNR. The list of priority species included in the 2014 West Virginia Invasive Species plan is still relatively up to date (as of 2020), but it is largely focused on the predominant Ohio River Basin concerns. Primary invasive species include

- Invasive animals, such as northern snakehead, rusty and virile crayfish, as well as goldfish and carp species, *Cipangopaludina chinensis* (Chinese mystery snails), Asian clams, and zebra mussels;
- Aquatic plants of highest concern (Threat Ranking 1), such as hydrilla, purple loosestrife, and yellow iris.
- Invasive microbes and pathogens are listed in this strategic plan; those mentioned include viral hemorrhagic septicemia virus, West Nile virus, *M. cerebralis* (the causative agent of salmonid whirling disease), and didymo. *Batrachochytrium* sp. (chytrid fungus) and ranaviruses are also mentioned as related to potential effects on amphibians.

Science Needs

Priority science needs as described in the management plan include early detection methodology, life history information, limiting factors for establishment, pathways and vectors for introduction and dissemination, and risk and vulnerability assessments. West Virginia DNR has expressed potential interest in research opportunities related to habitat suitability assessments and eDNA surveillance for northern snakehead in West Virginia waters.

District of Columbia (Department of Energy and Environment)

Overview and Management

Washington DC, which encompasses approximately 68 square miles within the Potomac River Basin of the Chesapeake watershed, has a vested interest in AIS management owing largely to species introductions by way of the Potomac and Anacostia Rivers flowing along and through the city. The Department of Energy and Environment (DOEE) within the Washington DC government addressed invasive species issues, including AIS, in its Wildlife Action Plan completed in 2015 (table 1B) and continues work to monitor and manage aquatic invasive species.

Invasive Species and Science Needs

Species of particular interest to DDOE fisheries management are three fish listed as priorities in neighboring States:

- Northern snakehead,
- Blue catfish, and
- Flathead catfish.

Acoustic tagging and telemetry are in use for all three fish species to monitor their locations and movement in these waters in and around Washington DC. Diet analysis to determine forage-based impacts of invasive catfish is within the scope of priority research for DDOE fisheries. Partner agencies and organizations for AIS research and management include FWS, National Oceanic and Atmospheric Administration (NOAA), MD DNR, and Virginia DGIF.

Pennsylvania (Department of Environmental Protection)

Overview

The Susquehanna River flows from New York through the entire length of the Commonwealth of Pennsylvania and into Maryland. There are approximately 21,000 square miles of drainage area of the Susquehanna River in Pennsylvania, representing about 76 percent of its total drainage area (Pennsylvania Department of Conservation and Natural Resources (DNCR), 2019). Another 1,570 square miles in Pennsylvania lies within the Potomac River Basin, and about 49 percent of the Commonwealth lies within the Chesapeake Bay watershed.

Management

Aquatic invasive species in general and within the Chesapeake drainage area are of high priority to the Commonwealth, as exemplified by its 2016 invasive species management plan (Invaders in the Commonwealth; table 1B) and the 2019 rapid response plan (Rapid Response Plan and Procedures for Responding to Aquatic Invasive Species in Pennsylvania; table 1B). The Pennsylvania Invasive Species Council is an intrastate organization that oversees and coordinates invasive-species-related activity in the Commonwealth. State-level agencies with regulatory authority include Pennsylvania Department of Agriculture, Pennsylvania Game Commission, Pennsylvania Fish and Boat Commission (PFBC), Pennsylvania Department of Environmental Protection (DEP), Pennsylvania Department of Conservation and Natural Resources (DCNR), Pennsylvania Department of Health (DOH), and Pennsylvania Department of Transportation. The DEP and PFBC, especially, have large roles in AIS management. These agencies partner with many other Federal and regional partners for AIS management, including USDA-APHIS, USDA FS, EPA, FWS, and the Susquehanna River Basin Commission. Representatives of these Pennsylvania agencies are members of regional conservation and AIS-based working groups including the mid-Atlantic Panel for Aquatic Invasive Species.

Invasive Species

As found in Invaders in the Commonwealth (table 1B), several AIS of particular concern in the Commonwealth and within or potentially within the Chesapeake Bay watershed include

- Aquatic plants: hydrilla, Eurasian milfoil, water chestnut;
- Aquatic invertebrates: New Zealand mud snail, zebra mussel, (**Fig. 6**) *Dreissena rostriformis bugensis* (quagga mussel), rusty crayfish;
- Fish: northern snakehead, and flathead catfish.

Additional AIS of concern in the Ohio River or Great Lakes drainage areas include the round goby and the viral hemorrhagic septicemia virus.

Science Needs

Priorities for AIS management as identified in the 2016 management plan include prevention through addressing the introduction of AIS at the sources and proactively providing education and outreach to enhance public awareness of the serious nature of the issue. Challenges currently facing Pennsylvania related to AIS management include insufficient tools to help prevent and control AIS dissemination. As with many other regional, State, and Federal agencies, increased funding would be helpful in addressing science and management issues related to AIS in the Commonwealth.

New York (Department of Environmental Conservation)

Overview

New York State includes headwaters of the Susquehanna River drainage area, and 2 of the 17 major watersheds within New York State (the Chemung River and the Susquehanna River watersheds) are part of the Chesapeake Bay drainage area. Aquatic invasive species represent a priority issue within New York State owing to its vulnerability as a point of entry for cargo and travelers and its proximity to major water bodies and waterways, including the Great Lakes, the Finger Lakes, the Atlantic Ocean, and the numerous canals that interconnect waterways within the State (NY DEC, 2015).

Management

In response to these particular vulnerabilities, New York has comprehensive AIS management as illustrated by the New York State Aquatic Invasive Species Management Plan (New York Department of Environmental Conservation, 2015; table 1B) and the New York State Partnerships for Regional Invasive Species Management implemented through the New York State Department of Environmental Conservation (NYSDEC; http://www.dec.ny.gov/docs/lands_forests_pdf/prismfs.pdf). The NYSDEC also maintains a web page with invasive species information, including a list of regulated and prohibited species for the State (NY DEC, 2019). New York State Office of Parks, Recreation, and Historic Preservation (OPRHP) is another State agency with vested interest in invasive species management. The OPRHP includes a statewide invasive species program with strike teams that function largely for invasive plant removal efforts. New York State also utilizes the NY Invasive Species Council, a statutory body for coordination of efforts among State entities and partners to address invasive species. The New York State Invasive Species Research Institute at Cornell University is administered and funded through NYSDEC to support invasive species research in the State; this institute has performed research related to biocontrol of invasive aquatic plants, such as phragmites. New York State has many additional Federal and regional partners in AIS research and management, including USGS, FWS, ACE, the Great Lakes Panel on Aquatic Nuisance Species (United States and Canadian membership representing governmental and non-governmental interests), and the Adirondack Watershed Institute (Paul Smith's College, Paul Smiths, NY). New York also has membership representation on the mid-Atlantic Panel for Aquatic Invasive Species.

Invasive Species and Science Needs

Species-based AIS priorities within the Chesapeake watershed for New York State include northern snakehead and hydrilla. The greatest perceived challenges related to AIS management include the human element from the standpoint of insufficient resources (staff and funding) and promoting behavioral changes in and around aquatic systems to prevent intentional and unintentional introductions of AIS. Education and outreach are high on the priority list for New York State AIS management. Other related science needs that were identified through documents and discussion include genetic analyses and biotyping as well as basic biological and life history information for AIS in the region.

River Basin Commissions

Overview

Interstate river basin commissions within the Chesapeake Bay drainage area operate interjurisdictionally to protect and conserve biotic and abiotic natural resources in their respective drainage areas. Follow-up discussions between USGS staff and representatives of river basin commissions representing the two largest watersheds of the Chesapeake Bay (Susquehanna and Potomac Rivers) yielded unique perspectives associated with regional river-based systems. The Interstate Commission on the Potomac River Basin (ICPRB) and the Susquehanna River Basin Commission (SRBC) work closely with State and Federal agencies on AIS-related issues, and both organizations consider AIS to be of general importance to the health of the river systems.

Figure 6. Dressenid mussels including *Dreissena polymorpha* (zebra mussel, pictured here) and *Dreissena rostriformis bugensis* (quagga mussel) were identified by regional State and Federal agencies as aquatic "red flag" species of concern. Although the mussels may not yet be present in a region, the potential for their presence is of heightened cause for concern owing to the possibility of serious consequences from their introduction. Image from https://nas.er.usgs.gov/taxgroup/mollusks/images/zebra16.JPG.

Invasive Species and Science Needs

Not surprisingly, the perspectives related to AIS issues for ICPRB and SRBC reflect the points made by the corresponding State representatives to USGS staff. Through these discussions, early detection and warning aids for proactive invasive species management needs, risk assessment factors, enhanced AIS monitoring capabilities, detection of pathways for pathogen introduction, and increased information on AIS distribution and abundance were all mentioned by ICPRB and SRBC representatives as informational gaps supporting management activity. Priority AIS mentioned specifically include

- Fish: northern snakehead and blue catfish;
- Aquatic plants: hydrilla and water chestnut;
- Algal organisms, such as didymo (**Fig. 7**).

Priorities for focus reflect the challenges expressed by each river basin commission. SRBC has a particularly unique challenge in reconciling fish passage needs related to restoration of important anadromous species (eel and shad) with containment of invasive fish, including northern snakehead and blue catfish, at four hydroelectric dam passage barriers on the lower Susquehanna River. ICPRB also identifies public awareness of potential AIS-related impacts as a challenge in keeping with education as a programmatic priority for this organization and with the widely expressed emphasis on a need for proactive management of AIS.

Federal Agencies—Department of the Interior

Overview and Management

In addition to USGS, six other Department of the Interior (DOI) bureaus and agencies play a substantial role in AIS science and management, including the Bureau of Reclamation (BOR), the Bureau of Land Management (BLM), the Bureau of Ocean Energy Management (BOEM), the Bureau of Indian Affairs (BIA), FWS, and the National Park Service (NPS). Both FWS and NPS are highly invested in AIS management within the Chesapeake Bay watershed, and both agencies work with the States and with other Federal entities, such as USGS, for AIS science in support of management needs. For example, along the Maryland reaches of the Potomac River, FWS and NPS personnel have worked together and with MD DNR to study effects of, and promote the fishery for, northern snakehead, one of the top AIS priorities in the region (A. Landsman, oral comm., October 2019). Representatives from both of these agencies also participated on the collaborative interagency Snakehead Plan Development Committee to produce

the National Control and Management Plan for Members of the Snakehead Family, *Channidae* (Aquatic Nuisance Species Task Force, 2014). Participation in the AIS scientific and management community is important to FWS and NPS, and both agencies have representation on the Mid-Atlantic Panel on Aquatic Invasive Species. The FWS representative co-chairs the ANS Task Force, and DOI has additional representation in this organization from multiple bureaus, including NPS, USGS, BOR, and BLM.

Invasive Species

Priority AIS for FWS and NPS reflect the concerns of the States regionally; priority AIS for these agencies include blue catfish and northern snakehead. The recent occurrence of blue catfish, including many young-of-year (YOY) specimens, in FWS river surveys for fish is regarded as a warning sign of their intense dissemination in tidal Chesapeake Bay tributaries (S. Minkkinen, oral comm, October 2019). The 2018 NPS publication "Biodiversity under siege: Invasive animals and the National Park Service" (Resnik, 2018) lists two AIS species among their top 10 invasive animal species named for the National Capital Region in 2016: the northern snakehead and *Trachemys scripta elegans* (red-eared slider). Blue and flathead catfish were also named in this list. Discussions between USGS staff and NPS personnel highlighted regional concerns related to aquatic invasive plants, such as hydrilla and invasive crayfish species, including the virile and rusty crayfishes (**Fig. 8**).

Science Needs

Science-related needs identified by both FWS and NPS personnel reflect the importance of proactive management and include risk assessment techniques to identify emerging AIS-related threats and enhanced monitoring capability, including eDNA and other information transfer methodology. Knowledge of pathogens and diseases potentially affecting native aquatic wildlife and associated with AIS dissemination was mentioned as a topic of concern and an information gap for DOI fisheries management. Agency representatives also identified funding and availability of resources for invasive species science, surveillance, and mitigation as further challenges facing DOI agencies related to AIS management.

Other Federal Agencies

Overview and Management

Federal agencies other than DOI are involved in AIS science and management in the Chesapeake Bay watershed, and their interests are represented by membership and involvement with interagency groups, including the ANS Task Force and the Mid-Atlantic Panel on Aquatic Invasive Species (MAPAIS). National Oceanic and Atmospheric Administration, ACE, U.S. Department of State, U.S. Coast Guard, U.S. Department of Transportation (DOT), EPA, and USDA are all examples of Federal agencies with AIS related interests. Within USDA, agencies have a broad spectrum of interests in, and priorities for, AIS. The Animal Plant Health Inspection Service in USDA is interested in AIS from the perspective of the health and well-being of

Figure 7. *Didymospherum geminata:* A, microscopic image of cells and B, macroscopic image of colony. Microorganisms in the aquatic environment were identified by State and Federal agency representatives as AIS of concern. Examples mentioned include a variety of animal pathogens in the aquatic environment and the diatom, Didymosphenia geminata, pictured in figure 7 and known collectively as "didymo" or "rock snot." Images from https://www.usgs.gov/media/images/diatom-didymosphenia-geminata-cell-wall (A) and https://www.nps.gov/grsm/learn/nature/images/large_rock_snot_4.jpg (B).

aquaculture species. The USDA Wildlife Services (WS) and Plant Protection and Quarantine programmatic elements work with AIS and species-specific projects that vary in geographic scope. The Forest Service (FS) within USDA has interest in invasive species, including AIS, within our national forests. The FS National Strategic Framework for Invasive Species Management (USDA, 2013) provides a written overview of invasive species management policy within the Service. Three large national forests—George Washington National Forest and Jefferson National Forest in Virginia, and Monongahela National Forest in West Virginia—are within the Chesapeake Bay watershed.

Invasive Species and Science Needs

Concerns regarding AIS, including invasive fish, mollusks, and plants, in mid-Atlantic national forests reflect those of the States in the region. As related through discussion with the FS representative, an intentional release of a species of Asian trapdoor snails in a remotely located recreational lake in the George Washington National Forest required significant time and effort for mitigation. Enhanced monitoring capabilities are recognized by USDA FS as a science and managerial need related to AIS. Because national forests often contain the headwaters of major river systems, biosurveillance for AIS in these forests may have important implications for entire watersheds. Interagency efforts to provide this type of biosurveillance may thereby serve all participants well, and Federal and State cooperation to fulfill this science need for proactive AIS management would be mutually beneficial.

U.S. Geological Survey Nonindigenous Aquatic Species (NAS) Database

The USGS maintains the NAS information resource, accessible at https://nas.er.usgs.gov/, for the purpose of providing an interactive platform for information related to nonindigenous aquatic species on a national scale. The NAS database was developed through the Aquatic Nuisance Species Task Force strategic plan (ANS Task Force, 2011) with the intension of developing a system to serve as a data repository for occurrence detection and reporting, and other information transfer. Information is maintained in the database for most freshwater and marine organisms in the Nation outside their native range. Sightings or collections of NAS may be reported online or by telephone, and the reported data are made available as part of the overall database for use by scientists, government agencies, and the general public. Note that the data accessed from this website are provisional in nature, and the data are provided "as-is" with no warranty. The data are not intended to be interpreted as a comprehensive or quantitative list of the NAS present in specified drainage areas because it is entirely dependent on the information provided to the database by a variety of sources. (Please see the complete USGS NAS disclaimer at https://nas.er.usgs.gov/disclaimer.aspx).

Queries of the database (July 2019) for each of the seven major HUC 6 drainage units within the Chesapeake Bay's watershed resulted in a long list of reported NAS for each drainage area. By selecting those species recently reported (since 2000) with clustered specimen records of greater than 20 and (or) widespread smaller occurrences evident within the drainage area, the species list for the Chesapeake Bay watershed, by HUC 6 drainage area, was condensed and included aquatic plants (n=5), invertebrates (n=9), fish (n=11) and one mammalian species (table 2).

Based on these parameters, qualitative observation of the available data in the NAS database largely supports the information gleaned from Federal, State, and regional partners related to AIS priorities. Plants widely reported to be present include the Eurasian watermilfoil, monoescious hydrilla, *Trapa natans* water chesnut, waterwheel plant, and *Nitellopsis obtusa* (starry stonewort). Most of these reports are from the four southernmost drainage areas. Invertebrate species widely reported to the NAS database include four species of crayfish: rusty crayfish, virile crayfish, red swamp crayfish, and *Procambarus zonangulus* (southern white river crayfish). These reports have come largely from the Upper Chesapeake and Potomac drainage areas and, to a lesser degree, from the Susquehanna River drainage area for the rusty crayfish. The Asian clam has also been widely reported to the database in 6 of the 7 HUC 6 drainage areas. The invertebrates widely and recently reported to the database include zebra mussel, quagga mussel, veined rapa whelk, and Chinese mystery snail, although reports of these invertebrates are more sporadic than those for the crayfishes and Asian clam.

Among fish species, the northern snakehead, blue catfish, and flathead catfish were repeatedly named as AIS priority species by State and Federal partners and were widely reported in the lower Chesapeake Bay drainage area. *Cyprinus carpio* (common carp) and *Carassius auratus* (goldfish) have been reported, mostly in the upper region of the Chesapeake Bay drainage area, including the Susquehanna River and Potomac River drainage areas. Several other fish species that were reported to the NAS database, but are not mentioned consistently as AIS priorities by partner agencies, include *Etheostoma zonale* (banded darter), *Etheostoma caeruleum* (rainbow darter), *Etheostoma blennoides* (greenside darter), *Notropis volucellus* (mimic shiner), *Ambloplites rupestris* (rock bass), and *Salmo trutta* (brown trout). Potential threats from other non-indigenous fish as invasive species are largely undetermined or related to potential competition or hybridization with native species. The lone mammal that was reported frequently is the nutria in the Upper Chesapeake and Potomac HUC 6 drainage areas.

Figure 8. Invasive freshwater crayfishes including *Faxonius rusticus* (rusty crayfish are prioritized as aquatic invasive species by multiple Federal and State agencies in the region. Image from https://nas.er.usgs.gov/XIMAGESERVERX/2018/20180409110033.jpg.

Commonalities and Conclusions

Among the 13 agencies and organizations queried by USGS staff on issues related to AIS (table 1A), there was variability in the managerial structure as well as the science and management needs and priorities communicated. Still, there was considerable commonality pertaining to the priority species and the management tools and approaches of most interest. All agencies and organizations (13) reported that AIS are of general concern, with most reporting AIS-related issues to be of high priority, including invasive fishes and invertebrates, invasive plants, and microbes including aquatic animal pathogens.

- Invasive fishes and invertebrates are of great concern to all partner agencies, and the northern snakehead and blue catfish are high priority to most of them, representing the two most named AIS of concern by these groups. Nine of 10 stakeholder groups listed northern snakehead as a high priority species, and 6 of these groups listed the blue catfish as a high priority species as well. Flathead catfish, invasive crayfish species (rusty and virile crayfish in particular), and dressenid mussels were prioritized by multiple partner groups, each receiving specific mention by at least 3 of the 10 stakeholder groups in discussions or documents. Invasive carp, such as silver carp, were mentioned by multiple agencies (3 of the 10 stakeholder groups) because they represent a priority AIS in other nearby watersheds and a threat for introduction and dissemination within the Chesapeake Bay watershed from these neighboring regions.
- Invasive plants are among priority species, and *Hydrilla verticillata* (hydrilla) topped the list. It was reported as a priority species by five of the stakeholder groups queried. Water chestnut, phragmites, and purple loosestrife were among the aquatic invasive plants prioritized by multiple partner agencies.
- Multiple stakeholder groups (5 of the 10 groups) also considered didymo and various aquatic animal pathogens among their priority AIS for management considerations.

Table 2. Nonindigenous Aquatic Species database-indicated aquatic invasive species of concern in the Chesapeake Bay watershed by Hydrologic Unit Code 6 Drainage (James, Lower Chesapeake, Upper Chesapeake, Potomac, Lower Susquehanna, West Branch Susquehanna, and Upper Susquehanna). Aquatic invasive species data were compiled from the U.S. Geological Survey (USGS) Nonindigenous Aquatic Species (NAS) database (https://nas.er.usgs.gov/, July 2019). Please note the USGS NAS disclaimer at https://nas.er.usgs.gov/disclaimer.aspx.

[Reports from within a hydrologic unit code (HUC) 6 region were designated as either moderate (*) or high (**) in occurrence for the tabulated data. Ches, Chesapeake; Susque, Susquehanna]

Taxonomic group	Common name	Scientific name	Watershed (HUC 6 drainage area)							Approximate introduction	Native range (River basins and drainage area)
			Upper Ches	Lower Ches	James	Potomac	Lower Susque	Upper Susque	Western Susque		
Water plant (5)	Eurasian water-milfoil	*Myriophyllum spicatum*	*			*				1950s	Eurasia
	Hydrilla (monoescious)	*Hydrilla verticillata*	*	*	*	*	*			1980s	Korea
	Water chestnut	*Trapa natans*	*			*				1800s	Eurasia
	Waterwheel plant	*Aldrovanda vesiculosa*		*						1990	Wide range (endangered in some areas)
	Starry stonewort	*Nitellopsis obtusa*						*		2011	Eurasia
Invertebrate (9)	Rusty crayfish	*Faxonius rusticus*	**			**	*	*	*	1995	Ohio River basin
	Virile crayfish	*Faxonius virilis*	**			**				1960s	Great Lakes and Upper Midwest
	Red Swamp Crayfish	*Procambarus clarkii*	**			**				1996	Gulf coastal plain & lower Mississippi
	Southern White River crawfish	*Procambarus zonangulus*	**			**				1996	Louisiana
	Asian clam	*Corbicula fluminea*	**	**	**	**	**		*	1975	Asia
	Zebra mussel	*Dreissena polymorpha*	*							2002	Eurasia
	Quagga mussel	*Dreissena rostriformis bugensis*					*		*	2000s	Eurasia
	Veined rapa whelk	*Rapana venosa*		*						1998	Western Pacific
	Chinese mystery snail	*Cipangopaludina chinensis*				*				1974	Southeast Asia

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[Reports from within a hydrologic unit code (HUC) 6 region were designated as either moderate (*) or high (**) in occurrence for the tabulated data. Ches, Chesapeake; Susque, Susquehanna]

Taxonomic group	Common name	Scientific name	Watershed (HUC 6 drainage area)							Approximate introduction	Native range (River basins and drainage area)
			Upper Ches	Lower Ches	James	Potomac	Lower Susque	Upper Susque	Western Susque		
Fish (11)	Goldfish	*Carassius auratus*	*			*	*		*	1980s	Eastern Asia
	Common carp	*Cyprinus carpio*	*			*	**	*	**	Late 1800s	Eurasia
	Northern snakehead	*Channa argus*	**	*		**	*			2002	Asia
	Blue catfish	*Ictalurus furcatus*	*	*	*	*				1970s	Mississippi River
	Flathead catfish	*Pylodictis olivaris*	*	*	*	*				1965	Mississippi and lower Great Lakes
	Banded darter	*Etheostoma zonale*					*	*	*	1978	Lake Michigan and Mississippi
	Brown trout	*Salmo trutta*	*			*	*	*	*	1990s	Eurasia
	Rock bass	*Ambloplites rupestris*				*				late 1800s	Midwestern U.S., Mississippi River
	Greenside darter	*Etheostoma blennoides*				*	*	*	*	1960s	Great Lakes and Mississippi River
	Rainbow darter	*Etheostoma caeruleum*				*				1996	Great Lakes and Mississippi River to Potomac
	Mimic shiner	*Notropis volucellus*					*	*	*	1977	Midwest and Mississippi River
Mammals	Nutria	*Myocastor coypus*	*			*				1940s	South America

There is considerable consistency in relation to the most pressing science needs to support AIS management among these stakeholder organizations in that the priority thematic element is one of proactive intervention to preclude AIS introductions and dissemination. It has long been recognized that the ecological and economic consequences of invasive species increase dramatically with time as the invasive species becomes established in a new habitat and niche (Cusack and others, 2009). The timeline of invasion for a species is often represented by a sigmoid curve, referred to as "the invasion curve," to figuratively represent the increased cost and effort required to control and manage invasive organisms with time, as well as the diminishing hope for successful eradication with time (**fig. 9**). The initial phase of invasion, including introduction and early recognition, is certainly the most ideal for the focus of AIS management efforts, and this is well reflected in the emphasis on proactive science and management priorities of the State and Federal agencies. Science needs to support management of invasive species that were recurrently indicated in discussion with agency representatives include

- Technology to enhance biosurveillance capability, such as reliable eDNA based detection methodology;
- Risk assessment modeling to forewarn of and prioritize AIS-related threats; and
- Increased information and intervention methods related to vectors and pathways of AIS introductions.

Increased information about the biology and life history of AIS was another focus of scientific priority; information related to trophic interactions, health and disease, and distribution and abundance were all mentioned by at least one stakeholder group as priority topics that would help management better understand AIS consequences. The potential applications of genetically based biocontrol mechanisms for AIS was another science related topic of interest expressed among partner agencies.

In addition to science-based priorities, the need for collaboration and communication among agencies and the general public was addressed in meetings and related documents. Partner agencies identified the value of further emphasis on public outreach and education pertaining to AIS. All Chesapeake Bay regional partners recognized and emphasized the need to communicate to the public the importance of AIS management and the crucial role of the public in prevention of AIS introduction and dissemination. Agency representatives pointed out that continued and augmented interagency collaboration between regional partners would be beneficial to help overcome personnel- and fund-related deficits to conduct biosurveillance or other AIS-related missions of an interjurisdictional nature.

Among State-level natural resource management, there is a range of infrastructural organization related to invasive species. All 6 States in the Chesapeake Bay watershed and the District of Columbia address invasive species in their biological resource management documentation; 6 of those 7 state-level agencies (including the District of Columbia) queried have AIS plans currently in place, planned, or under development. Three of the 7 also have formal interagency invasive species councils or matrix teams to address state-level issues, and all jurisdictions report that interagency cooperation is vital to their invasive species efforts. State and Federal agencies have multiple cooperative projects related to interjurisdictional AIS management, and USGS is involved in some of these efforts in the Chesapeake Bay watershed and other mid-Atlantic drainage areas as well. Currently, USGS scientists are working with MD DNR to investigate blue catfish occupancy and dissemination as well as trophic effects in Patuxent River, Md., and to enhance eDNA methodology for AIS detection for a suite of plant and animal species. USGS scientists are working with academia and VA DGIF on the novel water chestnut *Trapa bispinosa* as an emerging threat in the region and with members of the mid-Atlantic northern snakehead working group (FWS, NPS, MD DNR, VA DGIF, DC DOEE, DE DNREC) to identify pathogens of concern among this species. The interactive NAS database is a primary focus of USGS collaboration with Federal, State, and regional agencies to combat AIS in the Chesapeake watershed and well beyond because it is highly utilized by partners as they input data on invasive species collections and rely on the database for information on AIS presence in the region. Some jurisdictions in the region, including New York State and the Commonwealth of Pennsylvania, alternatively utilize the iMAPInvasives strategic management tool, and there is interest in coordination of these two platforms for invasive species information sharing for management applications (C. McGlynn, S. Pearson, I. Pfingsten, and others, MAPAIS meeting, oral commun., December 2019). There are other opportunities to continue with development and expansion of ongoing interstate and interagency collaborative efforts through other established organizations with vested interest in combatting AIS. One example is the Atlantic States Marine Fisheries Commission (asmfc.org) that unites Federal agencies and Atlantic coastal states to coordinate efforts for their common goals related to fisheries science, management, and conservation. Another such organization is the Chesapeake Bay Program (www.chesapeakebay.net), which has multiple Goal Implementation Teams (GITs) and workgroups for addressing specific regional issues. For example, the Invasive Catfish Workgroup within the Sustainable Fisheries GIT coordinates science among member agencies to address the consequences of invasive catfish species in the region. Continued and enhanced communication of USGS personnel with, or as members of, these organizations will help to recognize and promote related science needs for AIS management.

Aquatic invasive species issues, needs, and priorities in the Chesapeake Bay drainage area are further communicated interjurisdictionally through the ANS Task Force and its subgroup, the mid-Atlantic Panel for Aquatic Invasive Species. Established in 1990, the ANS Task Force is co-chaired by representatives of the FWS and NOAA and serves as an intergovernmental organization specifically operating to combat

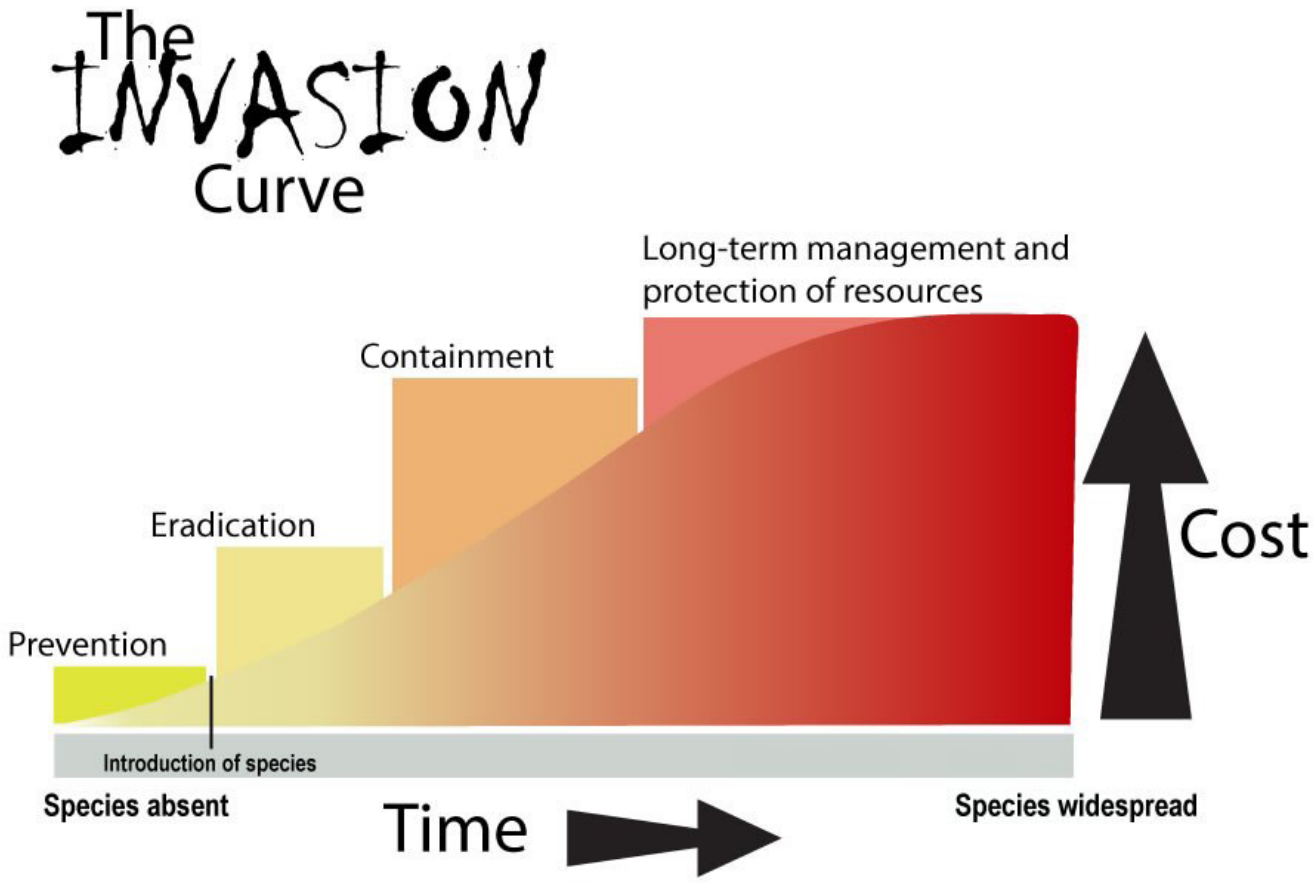

Figure 9. The Invasion Curve. From the National Park Service publication "Biodiversity under siege: Invasive animals and the National Park Service" (Resnik, 2018), https://irma.nps.gov/DataStore/DownloadFile/594922. The invasion curve illustrates changes in the ecological and economic repercussions of invasive species over time to emphasize the pressing need for early intervention to effectively manage invasive species and minimize their negative consequences.

aquatic nuisance species through the collaborative efforts of its member agencies. Six regional panels consisting of State, Federal, and regional representatives advise the ANS Task Force. The MAPAIS serves as 1 of those 6 advisory groups and has members from Delaware, Maryland, New Jersey, New York, Pennsylvania, Virginia, West Virginia, North Carolina, and Washington DC; the Chesapeake Bay watershed is represented entirely within the geographic scope of the MAPAIS. USGS currently has members on the ANS Task Force and the MAPAIS. The ANS Task Force has outlined six strategic plan goals for 2020–25 that provide a framework for collaborative efforts related to ANS science and management as follows: Coordination, Prevention, Early Detection and Rapid Response, Control and Restoration, Research, and Outreach and Education (ANS Task Force, 2011). The ANS Task Force also encourages the development of ANS specific management plans by States. Funding for ANS related problems is available under Section 1204 of the Aquatic Nuisance Species Prevention and Control Act for those States with management plans approved by the ANS Task Force. Currently, 4 of the 6 States in the Chesapeake Bay drainage area have ANS management plans in place (table 1B), and the 2 remaining States intend to develop their ANS plans in the near future.

Mid-Atlantic Panel for Aquatic Invasive Species—December 2019 Meeting

The ANS-related science and management priorities, communicated separately through these organizations, were further reinforced by the collective emphasis placed on them in the program of the December 2019 meeting of the Mid-Atlantic Panel for Aquatic Invasive Species. This MAPAIS semi-annual meeting was held in conjunction with a meeting of the Northeast Aquatic Nuisance Species Panel to address topics of mutual interest. Based on the presentations and follow-up discussions at the joint meeting and the MAPAIS semi-annual meeting, there is prioritized interest among committee representatives pertaining to vectors and pathways of

AIS introduction as well as tools for early detection, response, and reporting of AIS. Eradication programs were discussed, and the nutria eradication program on the lower Delmarva Peninsula was highlighted as an example of a successful effort to be expanded into other regions through interstate cooperation. The need for collaborative interagency efforts and funding to address AIS issues was a major thematic element of the meeting. One highlighted example is the emerging threat of *Trapa bispinosa*, a novel species of water chestnut in Potomac River tributaries, and the benefits of interagency collaboration for AIS science and management could well be applied to this issue. Additional topics like standardized eDNA tool development, boating vector management practices, and public outreach were addressed.

Next Steps

USGS scientists and research programs have a vital role in the effort to combat the dissemination and consequences of invasive species. It is advantageous for these highly collaborative efforts to continue in order to leverage the combined resources and further develop partnerships and capabilities in this capacity. Continued efforts to engage with partners to identify the most pressing science needs and the best ways to utilize the skill sets of USGS scientists to meet those needs will remain of critical importance. Active participation in task forces, panels, and other interagency working groups of a regional and national scope will help to facilitate communication among agencies and identify opportunities for focal- to broad-scope collaboration.

Some potential ways to address the most pressing science and management needs and priorities expressed by partner agency representatives in the Chesapeake Bay drainage area include the following:

- Development of biosurveillance and risk assessment tools for identification of AIS in proactive management;
- Development of proactive management techniques to prevent AIS introductions through recognized vectors and pathways;
- Development of interagency biosurveillance programs to best utilize personnel, funds, and other resources among interested agencies and organizations;
- Investigations to address life history, impacts, and movement/dissemination of top priority invasive species in the region;
- Investigations to determine the potential for application of synthetic biological (genetic) control methods;
- Investigations with focus on emerging and high priority AIS in the region, including fishes (blue catfish, flathead catfish, northern snakehead), invertebrates (invasive crayfish and mollusks), and plants (hydrilla, water chestnut, phragmites).

Public outreach and communication will likely remain as management related priorities for AIS and invasive species in general because public awareness and compliance are essential to prevent introductions and dissemination. Changing human behavior and practices related to AIS is a vital part of the overall conundrum, and the social science involved is as important as the biological and physical science for effective AIS management. USGS efforts to aid management through promotion of public awareness of AIS issues is therefore another important component of the overall agency role. Continued promotion of the NAS database as a tool for reporting AIS findings and as a repository of AIS-related information is important for its successful utility in the region and beyond.

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