Aquatic Invasive Species Research Report

Section 1108 of WRDA 2018

Prepared by the Assistant Secretary

of the Army for Civil Works

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Aquatic Invasive Species Research: Addressing the Spread and Impacts of Aquatic Invasive Species

This report describes ongoing and recently completed research activities performed by the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) related to the spread and impact of aquatic invasive species across the nation. A plan to address the spread and impact of aquatic invasive species is also provided, as directed in Section 1108(c) of the 2018 Water Resources Development Act.

Water Resources Development Act (WRDA) of 2018, Section 1108. Aquatic Invasive Species Research
Section 1108(a) of WRDA 2018, directs the Secretary to undertake research on the management and eradication of aquatic invasive species, including Asian carp and zebra mussels as part of the ongoing activities of the ERDC. In carrying out this research, the Secretary is directed to work with USACE District offices representing diverse geographic regions of the continental United States that are impacted by aquatic invasive species (Section 1108(b)). Section 1108(c) directs the Secretary to submit to the Committee on Transportation and Infrastructure of the House of Representatives and the Committee on Environment and Public Works of the Senate a report recommending a plan to address the spread and impacts of aquatic invasive species.

Background – Aquatic Invasive Species Impacts
Invasive species (aquatic and terrestrial) represent one of the most significant threats to our nation's natural resources, native species diversity, infrastructure, and economy. It is estimated that the introduction and establishment of non-native, invasive species into the United States has resulted in economic and environmental damages totaling $120 billion per year (Pimentel et al. 2005, ISAC 2017). An estimated $100 million is spent nationally to control aquatic weeds, a majority of which are non-native (U.S. Congress OTA 1993, Rockwell 2003). While the full extent of environmental impact is difficult to assess, invasive species have been identified as the second leading cause of threatened and endangered species declines after habitat loss (Chin et al. 2018). In addition to reducing native species diversity and habitat quality, invasive species also cause substantial damage to our nation's critical infrastructure. A recent review of the topic, reported that many types of federal infrastructure were impaired by invasive species including water, power, transportation and building systems (Vissichelli 2018). Federal agencies identified losses in asset value, lost service time and revenue, reduced operational capacities and efficiencies, and damages which increased safety and security vulnerabilities.

Over the past decade, the USACE spent on average, $138 million per year on activities to address invasive species (Figure 1). This includes activities for control and management, prevention, early detection and rapid response (EDRR), restoration, leadership and coordination, education and outreach, and research. Annually, the largest areas of investment have been for invasive species control and management (~45%) and prevention (~25%) activities. Approximately 4% of the total annual invasive species expenditure was invested in research. The USACE provides annual invasive species expenditure data to the National Invasive Species Council (NISC) for inclusion in the Interagency Cross-Cut Budget Report on Invasive Species Expenditures (https://www.doi.gov/invasivespecies/economic-costs-and-expenditures). The NISC develops an annual, federal agency invasive species crosscut budget report in response to Goal 2, Action Item 2.2.1, as outlined in the National Invasive Species Management Plan (NISC 2016).

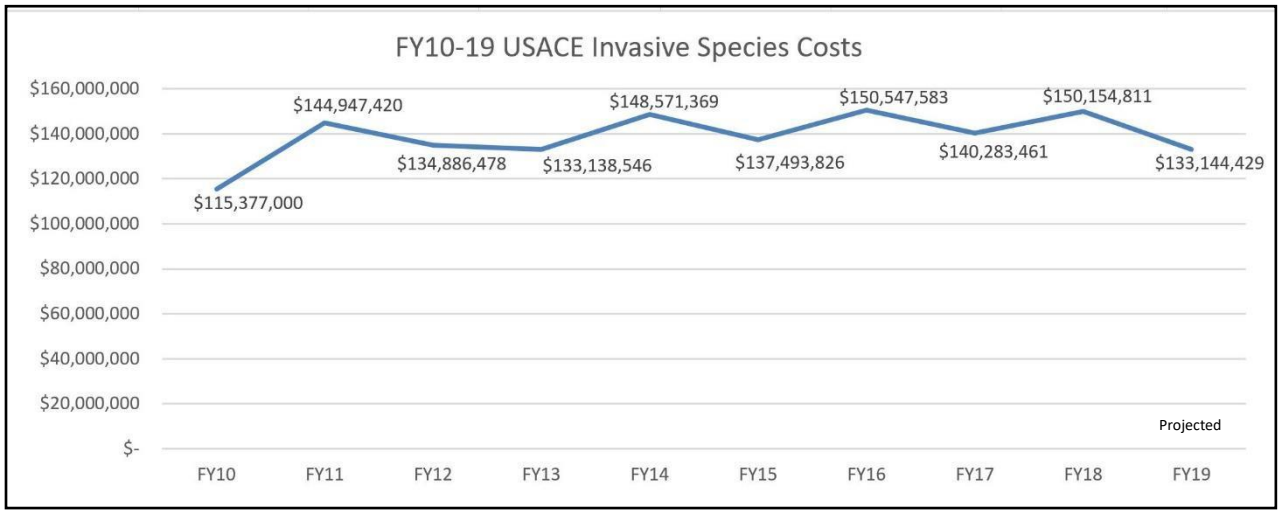


Figure 1. USACE annual expenditures associated with invasive species (both aquatic and terrestrial species) activities from Fiscal Year 2010 to 2019 (projected).

Aquatic invasive species (AIS) in particular, are problematic for USACE which manages a diverse portfolio of water resources, including more than 400 Civil Works lake and river projects in 43 states. Every USACE mission area and/or business line from Navigation to Flood Risk Management to Environmental Stewardship, is impacted by AIS. Nearly every aquatic ecosystem restoration project undertaken by USACE involves some form of invasive species consideration – whether species removal prior to restoration or management thereafter to prevent new invasions post restoration.

Figure 2. Water hyacinth blocking Lock & Dam #2 on the Arkansas River, USACE Little Rock District. Water hyacinth is an aggressive, invasive, floating plant; dense populations can weigh as much as 400 tons per acre. In 2017, this infestation caused an increase in lockage times, 2 to 4 fold.

Excessive growth of invasive aquatic plants (such as hydrilla, Eurasian watermilfoil, water hyacinth, water lettuce, and giant salvinia) obstruct flood control structures, water supply and irrigation intakes, reduce recreational opportunities, clog navigation channels, reduce functionality of miter gates on lock chambers, impede water flow capacity and storage, and cause build-up on trash racks. A secondary impact to the navigation community is increased lockage time and loss of revenue to the barge industry (Figure 2). Public health issues are also a concern as dense growths of floating vegetation can provide breeding habitat for mosquitoes and associated mosquito-borne illnesses.

Asian carp, sea lamprey, and suckermouth catfish are examples of invasive fish species present on USACE projects that require implementation of prevention or management strategies to mitigate impacts to operations (navigation, ecosystem restoration, and recreation) and to reduce negative impacts to native species. The USACE currently operates and maintains electric dispersal barriers in the

Chicago Sanitary and Ship Canal (CSSC) to prevent interbasin transfer of invasive fish, particularly Asian carp, between the Mississippi River and Great Lakes basins. The closure of the Upper St. Anthony Falls Lock in June 2015, helped prevent invasive carp and other AIS from gaining access to the upper Mississippi River. Additionally, USACE is evaluating potential control options and technologies at Brandon Road Lock and Dam on the Des Plaines River in Illinois to prevent upstream interbasin transfer of aquatic nuisance species. Effective barrier systems, sea lamprey traps, and the use of other AIS control measures are critical to maintain and preserve a healthy Great Lakes fishery which is valued at more than $7 billion per year (Great Lakes Fishery Commission 2019).

Invasive mussels (zebra and quagga mussels, also known collectively as Dreissenid mussels) are problem AIS for USACE. A recent survey found that 61% of responding Districts within the continental United States, reported zebra mussels in USACE managed waters (Hay et al. 2019). Dreissenid mussels foul critical infrastructure (gates, valve tunnels, timber cribbing on navigation structures, lock and dam surfaces, intake openings and pipes, cooling water strainers, water sensors, etc.), cause pitting and increase corrosion of hydraulic steel structures (Figure 3), reduce capacity for hydropower generation, and increase maintenance costs. The USACE Omaha District reported a 50% increase in operations and maintenance tasks at the Gavins Point hydropower facility due to zebra mussel and Asian clam fouling of raw water pipes in penstocks, heat exchangers and water cooling systems. Forced power outages to remove attached mussels from hydropower infrastructure translates into substantial losses in revenue. Recent reports by the Western Governors' Association (2019) and the Independent Economic Analysis Board (2010) estimate control costs could reach $500 million annually should invasive mussels spread to the Columbia River Basin. The Columbia River Basin is the last, major mussel-free system remaining in the continental U.S.; mussels pose a significant threat to USACE infrastructure valued in the billions at this locale.

Figure 3. Bulkheads at Elmsworth Lock and Dam, USACE Pittsburgh District, before (left) and after (right) removal of zebra mussels. Adult Dreissenid mussels (zebra and quagga mussels) attach to hard surfaces via byssal threads and can cause severe pitting and corrosion of hydraulic steel structures (right photo).

Invasive and nuisance algae are also problematic on USACE Civil Works projects. Toxic bloom events of golden algae have caused large-scale fish kills in Texas reservoirs in recent years. Starry stonewort, a grass-like, macroalga native to Europe and western Asia, is rapidly spreading throughout the central and northeastern states; however, little is known about its invasion potential and response to management tactics. While distributed worldwide, cyanobacteria or blue-green algae, such as *Microcystis* and *Anabaena*, can cause devastating bloom events which threaten aquatic ecosystems, present human health risks when toxins are produced, and cause major impacts to local economies. Harmful Algal Blooms (HABs) have increased in frequency, duration, and magnitude nationwide and across USACE-managed projects (Linkov et al. 2009, Herman at al. 2017) (Figure 4). USACE Districts experiencing HAB events reported impact to project operations, increased costs for HAB monitoring, beach closures, fish kills, modifications to water supply delivery, and decreased public visitation.

USACE Districts work collaboratively with state and local stakeholders when responding to HAB events, and on average respond to about 40 HAB events annually.

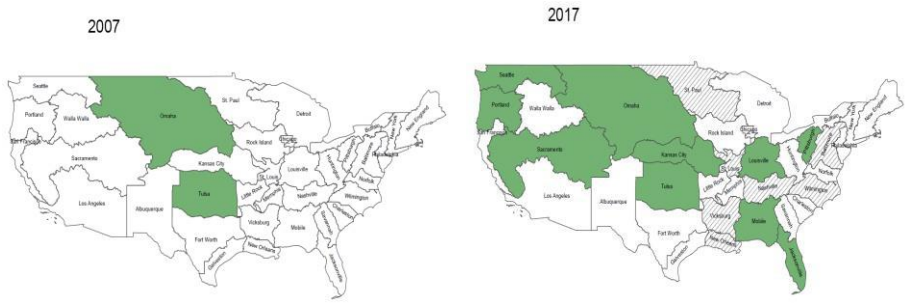


Figure 4. Survey results showing an increase over time of the number of USACE Districts reporting Harmful Algal Bloom (HAB) issues. Green: Districts reporting HABs; Gray: Districts reporting no HABS; White: No District response to survey.

WRDA 2018, Section 1108(a) and (b):
USACE Aquatic Invasive Species Research Programs

The USACE conducts research on AIS under two programs: the Aquatic Nuisance Species Research Program (ANSRP) and the Aquatic Plant Control Research Program (APCRP). Both programs are managed by the ERDC Environmental Laboratory and support USACE Operations. Through research, ERDC scientists are developing improved strategies for detection, prevention and management of AIS to reduce impacts on USACE operations and infrastructure and to restore ecosystem health and sustainability. Research priorities are based on field needs identified by USACE District and Division personnel, the USACE Invasive Species Leadership Team, the Environmental Community of Practice, and the Environmental Research Area Review Group.

The goals of these two research programs are similar:

- To provide science-based guidance on the use of new technologies for detection, prevention, management and monitoring of AIS that impact USACE projects;
- To reduce impacts of AIS on USACE missions and infrastructure;
- To reduce impacts on non-target species (i.e., Federally listed species);
- To reduce operations and maintenance (O&M) expenditures associated with management of AIS; and,
- To develop and disseminate useful solutions to end users.

A summary of these research programs, authorities and examples of how research supports reducing the spread and impact of AIS on USACE projects nationwide, are described below.

The ANSRP is a Remaining Item program in the USACE O&M Budget. This program is an expansion of the former Zebra Mussel Research Program, and addresses all invasive aquatic animals as well as cyanobacteria. The 1990 Non-indigenous Aquatic Nuisance Prevention and Control Act provided the initial authorization for this program, and directed research to be conducted exclusively on zebra mussels (Zebra Mussel Research Program). Reauthorization in 1996 under the National Invasive Species Act, expanded the program to include other taxa in addition to mollusks. The WRDA 2018 (Section 1109), further expanded program authorization to include research on improved strategies for early detection, prevention, and management to reduce the occurrence and effects of harmful algal blooms in our Nation's water resources. The current ANSRP research priorities are invasive fish (e.g., Asian carp, sea lamprey), mussels (e.g., zebra and quagga mussels), and harmful algal bloom species.

Asian Carp Research: Laboratory and field studies are ongoing at ERDC to investigate the management and containment of Asian carp species. Results of these studies have improved our predictive capabilities on invasion potential, improved operation of the CSSC electric barriers, reduced O&M expenditures, provided new guidance on design and efficacy of alternate deterrent systems, and enhanced support to the navigation and environmental missions for USACE. Ongoing research addresses four technical areas:

- *Electric Barriers:* ERDC scientists continue to support the development of improved strategies to prevent the movement of Asian carp into the Great Lakes. Asian carp research supports both the ongoing operations of the electric dispersal barriers at the CSSC and barrier design and planning alternatives proposed at the Brandon Road Lock and Dam. New operating parameters for the CSSC electric dispersal barriers under different environmental conditions (temperature and conductivity) has increased the performance of the CSSC barriers as well as decreased electrical requirements. Data provided justification to decrease voltage strength during winter conditions when water temperatures drop below 50˚F, saving USACE thousands of dollars in electricity usage. It is estimated that these new winter-time operating parameters will reduce electrical requirements by 25%. Research also found that spikes of increased water conductivity caused in increase in power requirements to near maximum capacity; this in turn, results in barrier operations to "fold back" either voltage strength or frequency of pulses. Research provided the needed data to support new "fold back" operating parameters to maintain optimal and effective barrier performance. Barrier support research is funded collaboratively by the ANSRP and the Great Lakes Restoration Initiative.

- *Hydraulic Barriers:* Studies to assess Asian carp swim performance, jumping abilities, fecundity, and population dynamics and understanding how environmental factors (water quality) can influence carp movement has provided an improved understanding of the biology and physiology of these species (Figure 5). Refined knowledge of swimming performance (speed, endurance, schooling effects) and leaping characteristics (speed, height, distance, angle) is critical information for developing effective physical (hydraulic and vertical) barrier design criteria and placement. The information is also useful for identifying risks to navigation and other public waters (i.e., likelihood of breaching barriers and expanding geographical range).

Figure 5. Fish biologists at the Engineer Research and Development Center utilize mobile and laboratory swim tunnels to evaluate swim performance (endurance, burst speeds, schooling effects and water quality effects) on different age classes (juvenile, sub-adult, and adult) of Asian carp species.

- *Coastal Rivers Invasion:* Research to assess the salinity responses of Asian carp (bighead and silver carp) to salinity will provide much needed information about salinity tolerance of these species and their ability to survive in brackish ecosystems. Results to date show that bighead and silver carp can survive salinity levels up to 12.5 ppt (parts per thousand); indicating brackish water does not limit Asian carp movement. Swimming performance of carp in water with salinity levels of 10 ppt was equivalent to swim performance in freshwater. These data underscore the high likelihood of survival and dispersal of Asian carp in estuarine environments especially during flooding events and floodway operations and provide increased awareness about the risk of estuarine systems as a potential trans-coastal conduit for carp dispersal.

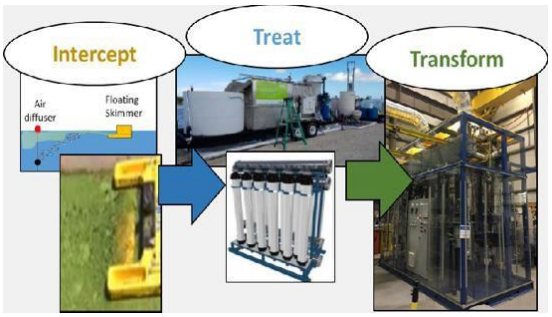
- *Impacts to Native Species:* Using a novel combination of bio-energetic and population models supported by a decade of field collected data and observations, ERDC fish biologists demonstrated that Asian carp cause long-term declines to native paddlefish populations. Paddlefish populations in prolonged contact with Asian carp are less robust (25% reduced weight) than paddlefish without recent contact with carp. Paddlefish are a federally-listed threatened species under the Endangered Species Act.

Zebra Mussel Research: Current antifouling techniques are limited to physical or mechanical removal of mussels from infrastructure and many of the existing coating technologies are not suitable for USACE hydraulic steel structures. Ongoing research in collaboration with the U.S. Bureau of Reclamation, will determine key factors that lead to bio-adhesion by zebra mussels and utilize this knowledge to develop new, anti-fouling coating systems that are non-toxic, durable and effective for minimizing corrosion and pitting caused by mussel adhesion. New anti-fouling coatings will reduce cleaning and maintenance costs, extend structure service life, reduce water conveyance issues in pipes, and improve overall operational reliability of infrastructure nationwide.

HAB Research: Understanding how and why HAB events (Figure 6) occur and the environmental factors that trigger bloom formation and toxin production are key to identifying best management practices for them. Collaborative research with the U.S. Geological Survey and academic partners is ongoing to study HAB dynamics in Lake Okeechobee, Florida. Intensive lake sampling coupled with manipulated mesocosm studies will assess the biodiversity of cyanobacteria and associated microorganisms at various phases of bloom events (pre-bloom, bloom, post-bloom), investigate the genetic basis for toxin production, and examine the role of environmental parameters and nutrients on bloom formation and decline.

Figure 6. Algal bloom in 2018 near the flood control structure at Port Mayaca, Lake Okeechobee.

This research will advance the scientific knowledge on key drivers and life cycle patterns of harmful bloom-forming cyanobacteria, enable improved prediction of bloom development, and identify potential targets for achieving successful bloom mitigation. Between the APCRP and ANSRP research efforts on HABs approximately $3,000,000 was executed on efforts to improve understanding, predictability, and control technologies.



Physical removal of algae and nutrients from a waterbody offers an alternative mitigation strategy for improving water quality and reducing impacts from HAB events. Scientists at ERDC-Construction Engineering Research Laboratory executed a pilot-scale research demonstration project in 2019 to assess the engineering performance and scalability of a new system for removing and disposing blue-green algae (cyanobacteria) from large waterbodies. The Harmful Algal Bloom Interception, Treatment, And Transformation System (HABITATS) has three key steps. The Interception step uses skimming technologies to selectively focus and remove algae at the water surface. The Treatment step uses physical clarification processes that separate the algae from the water, resulting in a concentrated algae stream and a clean water stream. In the Transformation step, the concentrated algae is converted to useful byproducts by an emerging technology called hydrothermal liquefaction. Hydrothermal liquefaction uses high temperature and pressure to break down the algae, toxins and other organic compounds and converts them into benign products that can be recovered for biofuels or fertilizer. The overall vision for HABITATS is to provide a rapidly, deployable solution for mitigating large HABs in an economically viable and sustainable manner.

The APCRP is the Nation's only federally authorized research program for invasive aquatic plant management and is nationally-recognized as the leader in aquatic plant management research and technology development. The APCRP is a component of the Aquatic Plant Control (APC) program, which also includes a cost-share program with state and local governments for conducting operational control of nuisance aquatic plants in non-federal, navigable waterways. The APC Program is a Remaining Item in the USACE Construction General Budget, and is authorized by Section 104 of the 1958 River and Harbor Act, as amended. For more than 40 years, the APCRP has provided research and technology development in the areas of: chemical, biological, mechanical, and integrated control; ecological studies and assessment; detection and vegetation mapping; and innovative synthetic biology approaches for invasive plant management. Presently, the program focus is development of best management practices for submersed, floating and emergent non-indigenous aquatic plants and algae including hydrilla, Eurasian watermilfoil and watermilfoil hybrids, flowering rush, yellow and crested floating heart, water chestnut, water primrose, alligatorweed, phragmites, Cuban bulrush, water hyacinth, water lettuce, giant salvinia, and starry stonewort.

Biological Control Research: Successful weed biological control relies on the identification and development of host-specific agents such as insect herbivores and pathogens. Agents are typically sourced from the weed's native range where natural enemies exist and keep weed populations in check. The goal of biological control is to reduce target weed populations to lower densities which minimizes their negative impacts to invaded habitats. To date, the APCRP has supported the development and successful permitting of more than 12 insect agents against invasive aquatic plants in the U.S. Biological control research funded by APCRP is conducted in collaboration with scientists at the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) Invasive Species and Pollinator Health Research Unit, USDA-ARS Australian Biological Control Laboratory, the Commonwealth Scientific and Industrial Research Organization (CSIRO), Centre for Agricultural and Bioscience International (CABI), Hankyong University, and the Chinese Academy of Sciences. Current

biological control research focuses on identifying and developing new insect agents against the monoecious biotype of hydrilla, phragmites, flowering rush, and yellow and crested floating hearts. There are currently no biological control options available for these invasive aquatic weed species in the U.S. Recent successes include a recommendation by the Technical Advisory Group for Biological Control Agents on Weeds (TAG-BCAW) for field release of two insect agents for control of phragmites. A TAG-BCAW recommendation is the first step for regulatory approval when seeking release permits in the U.S.

- *Insect Biocontrol Distribution Programs:* The APCRP provides funding support for insect rearing, collection, and release of three biocontrol insects through a nationwide Distribution Program. Any local, state, federal or non-government organization can request insects to initiate a new or augment an existing biological control program for the management of alligatorweed, hydrilla and giant salvinia. Over the last decade, USACE has provided millions of alligatorweed flea beetles, hydrilla flies, and salvinia weevils to agencies across the nation, and highlights USACE commitment to environmental stewardship. A recent video titled, "*Corps Tiny Weapon Winning the Biocontrol Battle*," describes the most successful of these distribution programs for managing alligatorweed. The video can be viewed at: https://youtu.be/Aqny06xTEXk

Figure 7. The alligatorweed flea beetle (left), hydrilla fly (center) and the salvinia weevil (right) represent three insect biocontrol agents developed through collaborative research funded by the Aquatic Plant Control Research Program.

- Chemical Control Research: Chemical control is a widely used strategy to manage invasive aquatic plants, and involves the application of registered aquatic herbicides, plant growth regulators, and algaecides. Chemical control research involves new product evaluation, understanding dose-response relationships, determining selectivity to non-target species, and developing new use patterns for existing products. Collectively, the data are used to provide science-based guidance to water resource managers for safely implementing chemical control programs to reduce invasive plant populations. One of the challenges when using aquatic herbicides to manage submersed vegetation in flowing water, is achieving sufficient herbicide-plant contact time for successful plant control. Ongoing research funded by the APCRP is investigating the innovative use of readily available, bubble barrier systems as a potential strategy to maximize plant control in flowing water systems. While the research is ongoing, the data show that deploying bubble barriers while applying an herbicide in high water exchange environments, can be beneficial for minimizing water flow, confining herbicide treatment thereby increasing herbicide contact time, and improving weed control. ERDC scientists are also investigating the utilization of this application method to restrict herbicides in a treatment zone as a way of minimizing potential herbicide impact to nearby sensitive, non-target plant species. This technology

when perfected, will result in less chemical input into the environment and could reduce time and cost compared to current aquatic plant management application techniques used in flowing water scenarios. To find out more about the use of this potential application strategy, view a recently produced video titled: *"Flowering Rush: Controlling an Invasive Species through Innovation and Partnership with Walla Walla District"* at: https://www.youtube.com/watch?v=fDWChNwJMIM

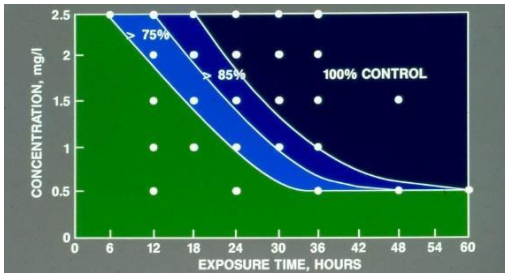


Figure 8. Concentration-exposure time requirements for the aquatic herbicide triclopyr to achieve 75, 80 and 100% of Eurasian watermilfoil.

ERDC scientists funded by the APCRP, are widely acknowledged for developing and publishing concentration-exposure time relationships for all of the available aquatic herbicides used in the U.S. and against all of the high priority submersed aquatic weed species (Figure 8). This information, paired with data on water flow characteristics (i.e. retention time), is key for decision making concerning product selection and effective rate of application, and saves millions of dollars annually in misapplication of aquatic herbicides.

Chemical management strategies are initially developed in the laboratory or in small-scale mesocosm studies at ERDC, with follow-on demonstrations at the operational field scale. Most recently, this lab-to-field concept was successfully deployed in partnership with the USACE Buffalo District, to eradicate a population of hydrilla on the Erie Canal and Lake Cayuga Inlet, New York. Herbicide treatment and application techniques developed in small-scale studies coupled with field data on water exchange were used to develop a prescriptive management plan to achieve an eradication goal. After five years of treatment and monitoring at these sites, hydrilla biomass and tuber numbers have been reduced by 98 and >99%, respectively.

Successful management at these locales significantly reduced the risk of hydrilla spread into the Great Lakes and other associated tributaries. This project was featured in a recent publication, "*Protecting What Matters – Stories of Success*," published by the National Invasive Species Council (Holland et al. 2018).

Ecological Assessment: Understanding the biology and ecology of invasive aquatic plants greatly improves the selection and timing of appropriate management options while minimizing adverse effects to non-target species that share the same habitats (Figure 9). Research in this area led to the discovery and documentation of hybridization between native and non-native aquatic plant species, herbicide-resistant hydrilla populations in Florida, morphological and genetic differences of water chestnut populations in the northeastern U.S., and knowledge on the genetic variability among flowering rush and alligatorweed populations. Awareness of these biological traits and attributes and how they affect performance of current management practices, is crucial for improving management practices, the timing of applying those management practices to achieve the best results, informs species risk assessments, and preventing further spread of AIS.

Figure 9. Dense hydrilla covers nearly 10,000 acres in Lake Seminole, Florida. Studies on the growth and life cycle of hydrilla demonstrated this aggressive submersed weed can grow both vertically and horizontally by up to 191 inches per day (Glomski and Netherland 2012). Extensive research on the biology and phenology of hydrilla has been instrumental in developing targeted management strategies for effective control of this species.

- Developing Innovative Management Strategies: ERDC scientists are collaborating with the U.S. Geological Survey and academic partners to develop gene-silencing technologies to manage invasive phragmites populations in the Great Lakes. While ongoing, the research has been successful in designing and testing cell penetrating peptides to deliver small regulatory RNAs into targeted cells of phragmites. Additionally, ERDC is developing similar technologies for disrupting photosynthesis and nitrogen assimilation in harmful algae species. These next generation gene silencing-based technologies may provide a new and environmentally benign solution for HAB and invasive aquatic plant management in the near future.

- Improved Vegetation Mapping and Monitoring Techniques: Accurate identification of some plant species can be difficult due to convergent evolution, phenotypic variation, age-related morphological changes and species hybridization. Taxonomic keys do not exist for populations that include native and invasive biotypes of the same species or subspecies. Since these biotypes and hybrids can respond very differently to management practices, it is important to equip field managers with the tools for accurate assessment and identification of problem plant species so that the best management solutions can be applied. ERDC is currently developing assays that can be incorporated in hand-held equipment for rapid detection and genetic discrimination between phragmites haplotypes found in North America. Methods to distinguish native from non-native haplotypes and hybrids will inform when and where to implement management.

  ERDC scientists are also developing improved remote sensing-based monitoring capabilities in response to episodic and rapid disturbance events through analysis of high resolution imagery to track and monitor aquatic vegetation. These methods will serve as a basis for deriving vegetation trend assessments and for integrating those results with landscape metrics to prioritize areas of concern for aquatic invasive species management and mitigation.

In summary, the ERDC will continue to provide science-based solutions to support USACE and the nation with actions to minimize the spread and impact of AIS on our nation's aquatic resources. While millions of dollars are spent each year to manage invasive species, the estimated benefits of management and control are undoubtedly much higher than these costs and demonstrate a positive return on investment (Rockwell, 2003, Lovell et al 2006, Olson 2006). The value of research guiding operational management has received less attention, but has also been shown to provide a

positive return on investment. A recently published economic analysis by Wainger et al. (2018), demonstrated that ecosystem service benefits of water hyacinth management greatly exceeds dollars spent for research to investigate how to control this nuisance plant species. An initial investment of $124 million by the USACE for research to develop effective water hyacinth management tools generated $4.2 billion in benefits to boating- dependent businesses, water treatment facilities and recreationists (Wainger et al. 2018).

WRDA 2018, Section 1108(c):
Recommended Plan to Address the Spread and Impact of Aquatic Invasive Species

The USACE continues to work nationwide to prevent and or slow the spread of AIS, and to reduce AIS impacts on native ecosystems within its legislative authorities and available appropriations. However, USACE recognizes that prevention, management and control of AIS are cross-cutting issues involving multiple agencies, and requires a coordinated, multi-agency response with federal, tribal, state and local jurisdictions. The two primary organizations created to facilitate this interagency coordination are: the National Invasive Species Council (NISC) via Executive Orders (EO) 13112 and 13751; and the Aquatic Nuisance Species Task Force (ANSTF) via Section 1201 of the Nonindigenous Aquatic Nuisance Prevention and Control Act. The USACE engages with these two interagency coordinating bodies and implements an Invasive Species Program that is consistent with the NISC National Invasive Species Management Plan (NISMP) and the Aquatic Nuisance Species Task Force Strategic Plan (ANSTF-SP).

In 2005, USACE established an Invasive Species Leadership Team (ISLT) to provide oversight of a comprehensive Invasive Species Program. The ISLT is a national, multidisciplinary team and is composed of one representative from each Major Subordinate Command (MSC) Division Office, a representative from one of the District Offices within each MSC, HQ USACE proponents, and Liaisons representing the research community from ERDC, the U.S. Department of Defense (DoD) Armed Forces Pest Management Board (AFPMB), and USACE representatives on the Interagency Working Group on Harmful Algal Bloom and Hypoxia Research and Control Amendment Act (IWG-HABHRCA). Team responsibilities include:

- Providing recommendations to HQ USACE staff on fulfilling agency duties under EOs 13112 and 13751
- Providing strategic direction to research programs that address invasive species including the Aquatic Plant Control Research Program and the Aquatic Nuisance Species Research Program
- Representing USACE on national and regional invasive species councils
- Coordinating and collaborating on national and regional invasive species councils, across Federal agencies, and with nonfederal sponsors
- Developing and implementing cost effective strategies to address invasive species problems that affect USACE water resource management missions
- Coordinating team initiatives with USACE Environmental (and other relevant) Communities of Practice (CoPs)
- Coordinating annual invasive species expenditures for USACE submission to the NISC

The ISLT follows a Program Management Plan (PgMP) which provides a framework by which the USACE applies invasive species policy to all of its activities. The PgMP also provides a strategy for addressing national invasive species policy issues affecting the USACE, and is meant to guide the implementation of national policy. In accordance with Engineer Regulation (ER)5-1-11, *U.S. Army Corps of Engineers Business Process*, the PgMP is revised as needed to reflect changes in strategy, funding and/or management goals. The focus of these actions is to foster sustainability, support the consideration of the environmental consequences of USACE activities, and to identify best management practices that support environmental and economic ideas to manage invasive species. The plan also fosters a collaborative manner across USACE business lines to protect Civil Works and Military missions while providing informational resources and points of contact to support our projects natural environments and lands. The ISLT reports to the USACE Chief of Operations on an annual basis and reports on progress toward achieving PgMP goals and objectives.

Goals identified in the PgMP correspond with the NISMP and the ANSTF-SP but specific objectives and action items under each goal were adapted for USACE. These objectives and corresponding action items are identified in the 2009 USACE Invasive Species Policy and have been refined by the ISLT. Each goal incorporates principles of an integrated pest management program using tools and strategies that work in concert with each other. The current plan with goals, objectives, and ISLT actions are summarized in the below table and will be implemented over the next five years (2020 – 2024).

GOAL 1: PREVENTION Prevention is the first and best line of defense against invasive species. Keeping invasive species out of an area avoids their adverse impacts as well as the costs to manage them. Once invasions occur, greater commitments of money, time, and other resources are required to reduce the harm caused. For some invasive species, there are no, or very few, tools available for their control once populations are established. Therefore, prevention is the most cost-effective and, in some cases, the only available approach.	
Objective 1: Identify pathways by which invasive species could potentially invade USACE and military lands as requested.	
Action:	
1.1.1	Identify pathways of invasion at USACE facilities
1.1.2	Document critical pathways via oceans, rivers, air, and land that have led to historic invasive species invasions
1.1.3	Create a library of existing risk assessments (National, Regional, Local) on the USACE Natural Resources Management Gateway
1.1.4	Conduct regional risk assessments to determine priority species at USACE managed facilities and areas

Objective 2: Take steps to block pathways that are recognized as significant sources for the un-intentional introduction of invasive species	
Action:	
1.2.1	Insert invasive species prevention language in applicable Engineering Regulations (ERs) and Engineering Pamphlets (EPs)
1.2.2	Promote boat inspection stations and boat wash stations at all USACE lake projects
1.2.3	Work with partners to support legislation to limit the importation of nonnative species
1.2.4	Conduct research on barriers to invasive species
1.2.5	Develop and implement prevention programs for identified priority invasive species and areas
1.2.6	Develop an alert system to warn projects of new species in their area
GOAL 2: EARLY DETECTION AND RAPID RESPONSE (EDRR) The next most effective strategy to prevention efforts, is detecting invasions and halting the establishment of additional invasive species through the development and capacity to identify, report, and effectively respond to newly discovered/localized invasive species. National coordination and communication among Federal and non-Federal entities increases the overall effectiveness of these efforts for invasive species management.	
Objective 1: Take steps to improve detection and identification of introduced invasive species and implement management actions to track invasive species data.	
Action:	
2.1.1	Develop monitoring plans for USACE managed projects and military lands as requested
2.1.2	Train staff in how to develop invasive species monitoring plans for USACE project lands
2.2.3	Promote and utilize USGS Nonindigenous Aquatic Species Alert System at all USACE projects http://nas.er.usgs.gov/AlertSystem/default.aspx
2.2.4	Disseminate and promote the utilization of existing databases (e.g., EDDMapS, USDA Plants Database, USGS Nonindigenous Aquatic Species Database
Objective 2: Develop a program for coordinating rapid response to invasion on USACE projects.	
Action:	
2.2.1	Develop a comprehensive EDRR plan for USACE
2.2.2	Inventory and post (or link) to existing Rapid Response Plans from partner Non-Government Organizations (NGOs), stakeholders, Federal, state, and local agencies on the USACE Natural Resource Management Gateway
2.2.3	Develop and implement emergency authority and funding mechanisms for rapid responses
2.2.4	Explore the potential to work with or leverage other Federal and state agency rapid response resources

Objective 3: Conduct appropriate research and development activities to ensure management programs are effective and science based. Sound scientific information is critical in guiding management activities, determining the magnitude of invasive species problems, planning future research and management programs, and improving intervention efforts.	
Action:	
2.3.1	Oversee the Aquatic Plant Control Research Program and the Aquatic Nuisance Species Research Program
2.3.2	Develop Statements of Need to address invasive species issues at USACE projects
2.3.3	Participate in and provide technical reviews of the annual invasive species research program reviews hosted by ERDC
2.3.4	Foster collaborative research and development with the Bureau of Reclamation and other Federal agencies to produce and infuse solutions for common invasive species challenges
GOAL 3: CONTROL, ERADICATION AND RESTORATION MANAGEMENT Control and wherever possible eradicate established invasive species populations and promote ecosystem restoration. Efforts to contain and reduce the spread and populations of established invasive species to minimize their harmful impacts should be planned using decisive actions and goals that employs an Integrated Pest Management (IPM) program and best management practices. Restoration to native species and habitat conditions, and rehabilitating high value ecosystems and key ecological processes that have been impacted by invasive species to meet desired future conditions should be foremost.	
Objective 1: Establish performance measures to determine the efficacy of prevention and control methods, and adapt and modify plans as necessary.	
Action:	
3.1.1	Develop a strategic plan for the implementation of the invasive species program to achieve, to the maximum extent practicable, a substantive annual net reduction of invasive species populations or infested acreage on land or water managed by USACE
3.1.2	Update USACE Engineer Regulations (ERs) and Engineer Pamphlets (EPs) to reflect the Invasive Species Policy
3.1.3	Provide strategic recommendations regarding invasive species policy to HQ USACE
3.1.4	Include invasive species monitoring and adaptive management measures and plans in planning study documents and risk registers
3.1.5	Consider invasive species in the NEPA process during project development
3.1.6	Discuss invasive species as a part of the AAR process
3.1.7	Ensure certified habitat evaluation models support quantification and evaluation habitat functions relative to invasive species

Objective 2: Develop and issue a protocol for ranking priority of invasive species control projects at local, regional, and ecosystem-based levels	
Action:	
3.2.1	Develop management checklist protocols that address prevention of re-infestations on project lands
3.2.2	Develop and distribute standard invasive species management recommendations for Regulatory use when evaluating permits and Civil Works projects
3.2.3	Compile information for a National report
Objective 3: Develop and implement control measures for invasive species in accordance with budget appropriations	
Action:	
3.3.1	Oversee the implementation of invasive species policy by MSC, Districts, and business lines
3.3.2	Advocate for adequate funding for existing invasive species programs at ERDC
3.3.3	Identify invasive species control as part of annual project lands budgets
3.3.4	Use the Operations and Maintenance Business Information Link (OMBIL) data fields so they reflect the information needed for accurate and usable reports
GOAL 4: COORDINATION AND COOPERATION Work strategically, use all USACE scientific, management, and partnership resources in unison to manage invasive species. Enhance the coordination and effectiveness of Federal programs to better leverage resources and fully engage state, tribal, territorial, and local governments and international and private sector partners. Use the best available science to guide management decisions, policy development, and provide authoritative information to the public.	
Objective 1: Partner/coordinate with local, State, Federal agencies and NGOs to manage invasive species at the project, regional, and National levels. Each ISLT member does this within their MSC/District and coordinates with other Districts in their MSC to do so.	
Action:	
4.1.1	Develop invasive species plans collaboratively with NGOs, State and local governments
4.1.3	Coordinate with the National Invasive Species Council on development and implementation of the National Invasive Species Management Plans
4.1.4	Develop MOUs and MOAs with partner agencies and NGOs
Objective 2: Minimize risks associated with pathways through public outreach. Provide education, communication, and interpretive programs to the public to gain their trust and assistance in the prevention, detection, identification, and control of invasive species.	
Action:	
4.2.1	Maintain and update the USACE invasive species web pages
4.2.2	Publish scientific findings in ERDC Technical Reports and scientific journals

4.2.3	Publish articles on invasive species management actions in District magazines
4.2.4	Embed invasive species management in existing USACE training (e.g., Prospect Courses)
4.2.5	Develop interpretive materials for field use

USACE District Responsibilities
The majority of invasive species management decisions are delegated to the District level. Funding is , determined through the Planning process with funding in the Investigations, Construction, or the Operations and Maintenance accounts. Projects are primarily budgeted at the District level.

Program and Project Risk Assessment. The risks of spreading invasive species should be considered during all phases of planning and review, Pre-Construction Engineering and Design, and Construction. Each District is responsible for assessing the risk to ensure that adequate controls are in place and operating effectively to safeguard government assets. Risk based analysis is used to compare plans in terms of the likelihood and variability of their physical performance, economic success, and residual risks. The total effects of risk and uncertainty on the project's design and viability can be examined and conscious decisions can be made reflecting an explicit tradeoff between risks and costs for, among other topics to include invasive species. A basic framework for quantifying invasive species risk was developed by the Aquatic Nuisance Species Task Force (ANSTF 1996).

Planning and Environmental Restoration/Mitigation Planning. When considering ecosystem restoration projects or in assessing mitigation alternatives, the opportunity to restore native species and habitats is considered for each project as appropriate. Mitigation measures may be authorized by Congressional legislation or approved by HQ as compensation for ecological resources unavoidably and adversely affected by a USACE project. Mitigation includes standalone projects; work undertaken concurrently with project construction; and operation, maintenance, and management of mitigation measures.

Usually, the species, habitat, and/or measures identified as mitigation are contained in feasibility reports and design memoranda submitted as supporting documentation for the project authorization and in other supporting documents such as special reports to Congress. All authorization documentation should also address local invasive species issues to include prevention, early detection and rapid response and explain how the project addressed these. The USACE is authorized by Sections 2036(a) and 2039 of the Water Resources Development Act of 2007 (WRDA 2007) to mitigate for fish and wildlife as well as wetlands losses and monitor and adaptively manage ecosystem restoration projects, respectively.

Operations and Maintenance

- **Master Planning:** Invasive species prevention, control and Integrated Pest Management (IPM) plans should be considered in Master Planning when appropriate. Master Planning involves the planning, design, and development of USACE controlled real estate following the process described in Chapter 3 of ER 1130-2-550. A Master Plan is a conceptual document guiding USACE responsibilities pursuant to Federal laws and regulations to preserve, conserve, develop, restore maintain, and manage the project lands, waters, and associated resources. The primary goals of a Master Plan are to prescribe an overall land and water management plan, resource objectives, land use classifications, and associated design and management concepts. The plan addresses all resources including, but not limited to, fish and wildlife, vegetation, cultural, aesthetic, interpretive, recreational, mineral, commercial, invasive species management through

prevention, detection and response planning and outgrant lands, easements and water.

- **Operation Management Plans:** Operational Management Plans (OMPs) are developed to address the operations, planning, real estate, safety, and public aspects of the project to accomplish the natural resources program objectives identified in the Master Plan. OMPs provide for monitoring project lands to determine unacceptable pest populations, including invasive species through early detection and response planning. OMPs already contain annual pest control plans for documentation of pesticide use.

- **Pest Control and Suppression Programs:** It is USACE policy to perform Integrated Pest Management (IPM) programs on Civil Works projects in a manner that provides for the safety of the environment, the public, and the pesticide applicator as described in ER 1130-2-540. This involves a comprehensive approach to prevent pests and disease vectors from causing unacceptable damage to operations, people, property, or the environment. Integrated Pest Management uses targeted, sustainable (effective, economical, environmentally sound) methods, including habitat modification, biological control, genetic control, cultural control, mechanical control, physical control, regulatory control and, when necessary, the judicious use of least-hazardous pesticides. Properly implemented IPM minimizes harm to human health and the environment; reduces the need for pesticides; reduces pest resistance; and minimizes pesticide waste as defined in ER 200-2-3.

Real Estate Outgrants. A Real Estate Outgrant authorizes the right to use federally-controlled real property. It is a written legal document that establishes the timeframe, consideration, conditions and restrictions on the use of Federal property. Invasive species prevention and control is a consideration in the development and execution of Real Estate Outgrants.

Regulatory. The USACE Regulatory Program protects the Nation's aquatic resources, while allowing reasonable development through fair, flexible and balanced permit decisions. The USACE evaluates permit applications for essentially all construction activities that occur in the Nation's waters, including wetlands. The invasive species policy applies to the Regulatory Program. The evaluation process for Department of the Army permits may address, through the appropriate public interest review factors (e.g., conservation, general environmental concerns), invasive species concerns in their analysis of impacts at the project site and associated compensatory mitigation projects. An appropriate level of coordination with Federal, state and local agencies will be used to develop those analyses. A Department of the Army permit may include special conditions to require the permittee to control the introduction or spread of invasive species at these sites.

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