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# Reducing the Risk of Invasive Pathogens to Wildlife Health in the United States

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# *Reducing the Risk of Invasive Pathogens to Wildlife Health in the United States*

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"Pathogen" means a bacterium, virus, or other microorganism that can cause disease. For the purpose of this paper, it includes all parasites.

"Host" means an organism that harbors and provides sustenance for a pathogen. Some hosts transmit pathogens to other hosts.

"Invasive species" means, with regard to a particular ecosystem, a non-native organism[1] whose introduction[2] causes or is likely to cause economic or environmental harm, or harm to human, animal, or plant health.[3]

## INTRODUCTION

The introduction of invasive species, whether intentional or unintentional, has the potential to adversely impact wildlife health. A diversity of non-native species displace (esp. through resource competition), hybridize with, or prey on native wildlife. They may also host and spread pathogens (Wilcove et al. 1998, Bellard et al. 2016, Roy 2016, Fisher et al. 2012, Roy et al. 2017, Smith et al. 2017).

Examples of invasive pathogens of native wildlife include:

- West Nile virus, first detected in the Western Hemisphere in 1998, devastated native avian populations in multiple regions of the United States. It can be transmitted by invasive mosquitoes (George et al. 2015).
- The re-introduction of the parasitic screwworm fly in South Florida in 2016 killed dozens of the highly endangered Key deer (*Odocoileus virginianus clavium*), making their small population extremely vulnerable to extinction.[4]
- Spring viremia of carp virus and viral hemorrhagic septicemia virus can have substantial impacts on a wide range of native fish that are ecologically and/or economically important (see case study in Annex 1).

Since the early 19th century, the threat of harm from invasive pathogens to wildlife health in the United States has steadily increased coincident with the rapid growth of trade, travel, transportation, and live animal industries. There are several pathways,[5] intentional and unintentional, for the entry and spread of invasive pathogens that impact wildlife. The commerce of non-native organisms, both legal and illegal, is of particular concern in the context of protecting native wildlife populations from invasive pathogens (Travis et al. 2011, Fisher et al. 2012, Jenkins 2012, Smith et al. 2017). By taking concerted measures to address the highest risk and most easily managed pathways, many of these threats can be mitigated. Primary, and thus priority, pathways include:

### Trade and Transport

*Importation of non-native animals for food and non-food purposes* – Hundreds of millions of live animals and animal parts are imported into and distributed within the United States, legally and illegally, each year. This includes pets, research subjects, zoological specimens, hunting trophies, food, and traditional medicines. The sheer volume of live-animal and animal-product imports into the United States challenges extant policies and practices to ensure that high-risk pathogens are not imported via these shipments. Although there are, ostensibly, health certifications and inspections required for some groups of organisms entering the United States (e.g., food animals, birds, primates), other organisms (e.g., most species of fish) do not require health certification to import.

1 "Non-native species" or "alien species" means, with respect to a particular ecosystem, an organism, including its seeds, eggs, spores or other biological material capable of propagating that species, that occurs outside of its natural range" (Executive Order 13751, 81 FR 88608, December 5, 2016).

2 "Introduction" means, as a result of human activity, the intentional or unintentional escape, release, dissemination, or placement of an organism into an ecosystem to which it is not native" (Executive Order 13751, 81 FR 88608, December 5, 2016).

3 Executive Order 13751, 81 FR 88609-88614, December 5, 2016.

4 https://www.fws.gov/refuge/National_Key_Deer_Refuge/News_Releases.html

5 Pathway means the mechanisms and processes by which non-native species are moved, intentionally or unintentionally, into a new ecosystem (Executive Order 13751, 81 FR 88608, December 5, 2016).

*"Hitchhikers" on non-animal products* – While the importation of live organisms is an obvious pathway for those organisms to become established in the United States, the importation of inanimate or inorganic goods and materials is another pathway for the introduction of invasive pathogens, which have found their way into the materials or the containers of these products. While inspections of the primary products might be conducted prior to, during, or following importation, the collateral cargo is often overlooked.

E-commerce and the direct online sale of foreign products present particularly high risks of invasive pathogen introduction and spread. Purchases of foreign goods, including live animals and animal products, may be directly sent from overseas sellers to United States purchasers, thus bypassing inspection and regulatory measures.

### Travel

*The global movement of military personnel, equipment, and material* – The engagement of the United States military around the world, with the related movement of personnel, facilities, vehicles, and resources, presents another opportunity for invasive pathogens to be inadvertently imported and spread. Although the military has some procedural requirements for cleaning and sanitizing transport containers, vehicles, and equipment when transported, these protocols are not tailored to address pathogens of native wildlife.

*International tourism* – Foreign travelers may enter the United States with goods or products that have not been scrutinized as deeply as other transactions and trade. Souvenirs, especially artwork, handcrafts, and similar items, can contain pathogens or other organisms carrying invasive pathogens.

## CALL TO ACTION

In keeping with action items 4.3.1 and 4.3.2 of the *2016–2018 National Invasive Species Council* (NISC) *Management Plan*, the Wildlife Health Task Team[6] of the Invasive Species Advisory Committee (ISAC) was charged with: 1) identifying the major areas of vulnerability to native wildlife from the introduction and spread of invasive pathogens, and 2) making recommendations to address these vulnerabilities, including through potential changes in statute, regulation, policy, or practice of the relevant agencies.

## FINDINGS

Although there are substantial resources deployed to prevent invasive species from entering the United States, substantial weaknesses and inconsistencies in current regulatory authority and practice remain (Reaser and Waugh 2007, Waugh 2009). Of particular concern in the context of this paper is the virtual lack of comprehensive regulatory authority for any agency to directly address the importation and spread of invasive pathogens into the United States that might harm native wildlife.

Although the impacts of invasive pathogens on wildlife health are well recognized, our findings indicate that the federal government currently lacks the capacity to: 1) identify the real or potential human source(s) of introduction of invasive pathogens and hosts of those pathogens; 2) identify and understand the harmful effects of invasive pathogens on wildlife health;[7] 3) prevent the introduction of potentially invasive pathogens and their hosts that could harm native wildlife; 4) recognize and isolate those invasive pathogens and their hosts where they might enter the United States; and 5) respond to the introduction of invasive pathogens and their hosts, as well as subsequent disease outbreaks.

To address these concerns and achieve the goals of Executive Orders 13112 and 13751, federal policy and practice must protect native wildlife from the importation and spread of invasive pathogens, recognizing that invasive pathogens:

- Can have direct and secondary impacts on native wildlife, including native pathogens (which might become more virulent), and
- May be transported via a wide range of living (e.g., non-native wildlife, domestic animals, plant materials) and non-living (e.g., shipping materials) conveyances, typically associated with human activities.

Various regulatory and non-regulatory mechanisms exist to limit the introduction of invasive species into the United States (Reaser and Waugh 2007, Waugh 2009, Reaser et al. 2003). While many are intended to interdict invasive organisms in a general way through import prohibitions, declarations, inspections, and monitoring, few are specifically intended to prevent or eliminate threats to native wildlife health from invasive pathogens, and even fewer are uniformly effective. The following four approaches constitute the major facets of the United States' strategy for preventing the introduction of invasive species at ports of entry:

1. *Pre-export inspection, quarantine, and certification* – These inspections take place in countries of origin. They might or might not include health certification for live or dead animals. In cases of pre-export inspection and certification implemented to protect wildlife health, this tool is not often used to reduce risk. Moreover, it has only been applied to a few taxa (e.g., salmonid regulations under the Lacey Act, 18 U.S.C. §42 *et seq.*) and rarely for invasive pathogens. For certain live animals, especially domestic animals, livestock, and poultry, specific vaccinations or parasite examinations might be required. For shipments likely to include organisms that threaten agriculture

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7 Although this is also true for secondary harm to the broader ecosystem, the economy, human health, and domestic animal health, this paper explicitly focuses on invasive pathogens that impact wildlife health and that are not already covered by authorities relevant to the other types of impacts.

or human health, actions may be taken to inspect and treat the shipment, including the various containers or equipment used during transportation. However, the inspections are primarily limited to the act of verifying that the list of animals, plants, or other export products and materials is accurate. Rarely, do they include searches for pathogens carried by the exported animals or potentially contaminated shipping containers.

2. *Import prohibitions* – Several extant laws and regulations authorize federal agencies to prohibit the importation of non-native animals. Two of these allow for risk management actions, such as quarantine. The Public Health Service Act (42 U.S.C) authorizes Human Health and Services' (HHS) Centers for Disease Control and Prevention (CDC) to promulgate and enforce regulations to prevent the introduction, transmission, or spread of pathogens that can affect humans. The Animal Health Protection Act (AHPA; 7 U.S.C. §8301 *et seq.*) authorizes the U.S. Department of Agriculture (USDA) to enforce regulations to prevent the introduction, transmission, or spread of any pest or disease of livestock and certain species of wildlife (9 CFR). AHPA does not include a mandate specific to wildlife or to invasive pathogens thereof, nor does USDA have a mission-related priority to address pathogens affecting native wildlife health.[8] Moreover, while the Lacey Act (18 U.S.C. §42 *et seq.*) authorizes the Department of the Interior's Fish and Wildlife Service (USFWS) to prevent the importation of potentially harmful *species,* there are no analogous statutes that authorize the management of invasive pathogens that affect wildlife populations. Furthermore, the ability of the Lacey Act to prevent the transport of invasive species was changed in 2017 when the Circuit Court of the District of Columbia held that the United States federal government lacks the authority, under the "shipment clause" of the Lacey Act (18 U.S.C. §42[a] [1]), to prohibit shipments of "injurious species" between the "continental" states (United States Association of Reptile Keepers, Inc. v. Zinke, 852 F. 3rd 1131 [2017]).
3. *Inspections at ports-of-entry* – When goods imported to the United States arrive at the various official ports of entry, they are subject to inspection by several United States agencies (e.g., CDC, USFWS, USDA's Animal and Plant Health Inspection Service [APHIS], Department of Homeland Security's [DHS] Customs and Border Protection [CBP], the HHS' United States Food and Drug Administration [FDA]). The volume of imported goods is so large that typically only 2% of containers are ever inspected, although the number may be substantially higher for certain shipments for random sampling (Reaser and Waugh 2007). For many animals that are imported into the United States, USFWS port inspectors do not even have the authority to stop shipments even with evidence of diseased organisms.
4. *Post-import inspection and quarantine* – For certain types of imported plants and animals, various federal and state agencies can require that they be isolated, quarantined, or more thoroughly examined by agents at the import destination. In certain instances, USDA post-entry quarantine is mandated (9 CFR Part 93). This can follow routine inspection at ports of entry. However, having no mandate for surveillance or management of potentially diseased imports of live, non-native species of fish or other wildlife, the USFWS has neither the veterinary expertise nor quarantine facilities to evaluate or detain shipments of live animals for which they have primary responsibility.

In 2010, the Government Accounting Office (GAO) issued a report to the Senate Committee on Homeland Security and Governmental Affairs (GAO 2010). The authors reviewed the importation of all live animals, for all purposes (e.g., food, resale, scientific use or research, educational use). The GAO identified four agencies (CBP, APHIS, USFWS, and the CDC) that share primary responsibility for inspection and management of those animal imports. The findings of that report itemized large gaps and inconsistencies in statutory authority, the failure or inability of the various agencies to work effectively and collaboratively with each other, and a basic lack of shared goals related to protection of the United States from diseases that may come into the country via live animal imports. It concluded that unless and until those gaps in authority and function were corrected, human health, domestic animal and livestock health, and wildlife health would remain at substantial risk.

While preparing this white paper, ISAC evaluated many of the same agency functions and procedures that were included in the GAO report. It is clear that only minimal changes to laws to prevent or manage invasions of the United States by invasive pathogens and related threats to native wildlife species have been made since the GAO report was issued. Moreover, few of the GAO recommendations have been implemented by the respective agencies. Our findings indicate that federal agencies—individually or collectively—do not have the comprehensive authority, responsibility, or technical capacity to protect native wildlife from the direct or indirect threats posed by invasive pathogens. Several aspects of the current approaches to invasive species prevention, eradication, and control, especially those regarding invasive pathogens, remain particularly troublesome and challenging. The following needs were identified:

1. *Consistent levels of regulatory authority among agencies* – There is disparity of inspection, regulation, and management between certain types of imports in the regulatory authority granted to various agencies. For example, the USFWS has the authority to inspect all shipments of wildlife imports to the United States, but that authority extends only to whether the shipment contains the allowed or declared species. And, though the USFWS has standards for the humane and healthful transport of wild mammals and birds (e.g., *see* 50 C.F.R. part 14, Subpart J), these standards do not apply to all groups of organisms. Moreover, the USFWS does not have specific authority to

8 Control of diseases affecting livestock and poultry could secondarily protect wildlife in cases in which those disease are also transmittable to wildlife. However, this is not USDA's delegated mission and some invasive pathogens impact wildlife without posing a risk to livestock or poultry.

detain, confiscate, or quarantine shipments of diseased animals. Consequently, compromised or contaminated shipments can pass through ports of entry, or continue to domestic destinations.

2. *Alignment of agency authority and agency practice* – There are serious differences between the legal authority granted to a specific agency to inspect, certify, confiscate, quarantine, and otherwise regulate imports for which they may be responsible and the actual exercise of that authority. USDA has legal authority to inspect and regulate the importation of all live animals that might be infected with pathogens harmful to livestock. In practice, however, USDA generally confines its activities to livestock, poultry, and other food animals or pathogens that might cause disease in domestic livestock or other agriculture (See 9 CFR). Inspections of other animals and plants are referred to other agencies. If inspectors from other agencies are available, this may be less troublesome. But if personnel from those agencies that have primary authority are not available, shipments might simply pass through ports of entry or other inspection facilities without being inspected.
3. *Coordination of effort among agencies* – There appears to be no mandated cooperation or coordination among agencies to ensure that inspectors with appropriate expertise and necessary authority are available or that they prioritize the inspection of shipments that are high risk for the importation of invasive pathogens. This lack of coordination may be a simple failure to coordinate work schedules among government inspectors, but it can also include failure to share information about shipments that may be of primary interest to another agency due to risk relevant to their mission areas. Respective agencies do not have uniform processes to sufficiently ensure implementation of import requirements. There is no single application process for requesting clearance from multiple agencies with overlapping jurisdiction and no streamlined interagency process to delay or stop a shipment in transit.
4. *Standardized risk analysis and horizon scanning* – Federal agencies lack a standardized approach to the invasive species risk analyses and horizon scanning protocols needed to effectively project the likely impact of invasive pathogens on native wildlife and target federal resources accordingly. Due to the potential for invasive pathogens to spread rapidly, a "decision support toolkit" needs to include the capacity to conduct cost- and time-efficient rapid analyses (screenings), as well as in-depth evaluations for organisms of particular concern. Poor federal investments in invasive species information systems (esp. data on the occurrence and impacts of invasive pathogens, their hosts, and impacts) and research further hamper the federal government's capacity to project invasion risk and impact (Meyers in prep).
5. *Adequate pre-export safety requirements in countries of origin* – There are few effective requirements or procedures to minimize the likelihood that animals directly imported into the United States will undergo adequate health evaluation, prophylactic treatment for pathogens, or acceptable periods of quarantine. In many exporting countries there are no controls, robust or otherwise, to prevent the coincident export to the United States of invasive pathogens that could harm native wildlife.
6. *Single federal standard for labeling, health certification, reporting, or the provision of other important data about shipment* – Similarly there is not a single standard for permits or processing. Different countries, and different United States import control agencies, typically have entirely different registration and report forms and requirements for shipments bound for the United States. Even the primary agencies of the United States government charged with port security and import inspection cannot easily share information about shipments or identified threats of which inspectors need to be aware.
7. *Rapid response capability to deal with invasive pathogens and consequent outbreaks of disease* – The federal government has a very limited capacity to rapidly respond to and eradicate, mitigate, or manage invasive pathogens before they spread. Response to any outbreak remains a multi-agency, labor-intensive undertaking that normally requires coordination with state agencies where an outbreak occurs or is expected to occur. A One Health approach[9] to responding to invasive pathogens could increase federal capacity to reduce disease risks to wildlife, as well as people and domestic animals.

## RECOMMENDATIONS

In general, federal agencies lack the clear authority, mandatory coordination, and accountability necessary to prevent and manage invasive pathogens of wildlife. Native wildlife is thus vulnerable, as are all the vital systems secondarily impacted. ISAC, therefore, recommends that NISC direct federal agencies to, in accordance with their mandates and authorities, implement the following actions as a matter of priority:

### Recommendation 1

*Conduct a comprehensive law and policy audit[10] for each relevant agency to determine their capacities and enactment practices to address invasive pathogens of wildlife.* This audit should include a "real-world assessment" of how much of each agency's respective authority is actually used and carried-out relative to invasive pathogens of wildlife that might be imported with shipments of wildlife and wildlife products or other shipments entering the United States. An assessment of areas in which traditional programmatic priorities might differ from full statutory authority should be included.

This comprehensive review will enable federal agencies to:

9 This includes the integration of efforts aimed at threats of invasive pathogens that affect the health of humans, domestic animals, wildlife, and the environment (e.g., www.onehealthinitiative.com).

10 To include statutory authority, regulations, legal mandate, and internal policies and priorities.

a) Identify the existing gaps in coverage, protection, and response capability for addressing invasive pathogens that impact or are likely to impact native wildlife;
b) Determine if gaps exist in statutory authority, budgetary capacity, or administrative discharge of existing authority, and develop strategies and tactics to resolve these gaps to reduce vulnerability and harm to native wildlife;
c) Identify opportunities for current programs and practices to be more collaborative, effective, and efficient, including the generation of formal agreements amongst NISC members, and between federal agencies and state and local partners; and
d) Create a publicly accessible directory that indicates which agency has the lead for addressing invasive pathogen threats to native wildlife, noting relevant authorities, regulations, and technical capacities.

**Recommendation 2**

a) Ensure effectiveness and cost-efficiency by increasing institutional coordination and collaboration. This necessitates that federal wildlife health initiatives are integrated into a "One Health" approach backed by adequate informational, technical, and financial resources;
b) Promote collaboration among federal, state, territorial, tribal, and local government entities to address issues involving invasive pathogens and wildlife disease. This includes coordination of activities and authorities,[11] the sharing of expertise and resources, and implementing a system and culture of cross-reporting for all relevant agencies to ensure that all potential threats and vulnerabilities are identified, assessed, and addressed;
c) Establish port/border security procedures and protocols that are uniform across all agencies and all ports of entry, to facilitate coordination, sharing of facilities, equipment and personnel, and to optimize the effectiveness of government response strategies and tactics;
d) Re-establish regular multi-agency port meetings, trainings, and other effective strategies to ensure that relevant agencies (federal, state and local), custom brokers, transport companies, importers and other affected stakeholders are fully informed about priority wildlife disease issues in order to achieve full and effective compliance with regulations, procedures, and other processes. Emphasize how protecting wildlife protects public health, the environment, and agriculture;
e) Establish comprehensive, multi-agency training programs to ensure that all inspection personnel are cross-trained to recognize and respond to the full spectrum of risks, institute interagency response teams, regardless of which agency has primary responsibility for surveillance and response, and provide site-specific training at each point of entry to identify, isolate, and contain risk or threats until they are appropriately resolved; and
f) Foster inter-agency public education programs to increase public awareness of, and support for, the need to prevent the introduction of invasive pathogens that might harm native wildlife. Campaigns will need to be audience-targeted and employ traditional education and outreach approaches, as well as emerging social media technologies and platforms.

11 Execute appropriate agreements (MOUs) to share authority, responsibility, personnel, and resources.

**Recommendation 3**

*Develop and implement a risk-based early detection and rapid response strategy to identify, contain, and eradicate invasive pathogens that enter the United States, before they become established or cause extensive harm to wildlife populations.*

a) Create and implement risk-based response strategies and tactics to proactively scan for and respond to potential threats before invasive pathogens arrive at United States ports or become established within the United States. This should include federal action to establish the:
   i) Capacity to implement emergency inspection or certification procedures prior to allowing exports bound for the United States to leave the country of origin, or to prioritize specific types of shipments, or shipments from targeted regions that arrive at United States borders.
   ii) Authority to designate prohibited species or cargoes on an emergency basis, and to rapidly establish and implement surveillance and response strategies for any threat to wildlife health, as appropriate. If the extent of a threat might exceed the rapid response capabilities of a single agency, or overwhelm the resources in a particular location, action thresholds and contingency plans should be developed that could use the full range of biosecurity threat responses available to the federal government;
b) Create the capacity and facilities at ports of entry to detain and effectively isolate or quarantine shipments that might contain invasive pathogens that may harm native wildlife; and
c) Increase federal government support for research to identify appropriate risk management actions that can be taken to address invasion pathogen risk pre- and post-entry into the United States.

**Recommendation 4**

*Identify, or create and deploy applied information tools, databases, and reference resources for use by inspectors and other stakeholders to ensure that the most current and comprehensive information related to invasive pathogens and wildlife health is available, and is being fully employed.*

a) Promote uniform, compatible, and publicly accessible databases related to wildlife health by all relevant federal and state agencies, including information on all regulated activities associated with invasion pathways (e.g., scientific research, scientific collection permits, wildlife rehabilitation, educational use and display, captive breeding, incidental take);
b) Facilitate efficient sharing of information related to in-

vasive pathogens and wildlife disease among member agencies and entities, and between the federal government and states, territories, tribes, and other wildlife and health agencies at the international, national, regional, or local level;

c) Create applied information tools for invasive species of concern, using existing resources (e.g., World Organization for Animal Health [OIE], APHIS, National Association of State Health Veterinarians, Wildlife Disease Association, National List of Reportable Animal Diseases, ProMed, WILD-ONE) that can assist personnel in the field (e.g., biologists at deer check stations, wildlife veterinarians and rehabilitators, resource managers) identify and respond to invasive pathogens; and

d) Promote implementation of an eDocs system for submitting Declarations for Importation or Exportation of Fish or Wildlife (3-177), health certifications, and permits to assist with the identification of wildlife health risks.

**Recommendation 5**

*Develop and deploy advanced technologies needed to facilitate identification and eradication of invasive pathogens that might harm native wildlife* (e.g., molecular-based surveillance, thermal scans, eDNA, rapid screening, and other new and emerging technologies).

a) New technologies must be developed, evaluated, and validated before use in a regulatory environment;

b) Methods of destruction of invasive pathogens without harming the animals or products imported should be developed and after proper training, applied; and

c) Ensure that these technologies are known, available, and fully used at all inspection facilities, and that personnel from all agencies are able to access them.

When considering these recommendations, NISC is encouraged to recognize the cost-efficiencies of preparedness and early response. A cost-benefit analysis of the actions recommended herein would help identify and prioritize those measures that can be implemented with existing resources, as well as make the case for those that will require new or additional funds.

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# *Annex I: Fish Virus Case Study*[12]

Two globally important, highly contagious, and virulent fish viruses are excellent examples of pathogens that affect both native wildlife (wild fish) and cultured aquatic livestock. Spring Viremia of Carp Virus (SVCV) and Viral Hemorrhagic Septicemia Virus (VHSV) cause significant fish losses, and are World Organisation for Animal Health (OIE) reportable, meaning that any findings of these viruses must be made known to the animal-health competent authorities in the affected country. While the modes of introduction of these two viruses into the United States differed, in both cases the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) responded to the disease outbreaks. APHIS has authority to prevent the spread of the diseases, even though VHSV was not, and to date has not been, found on fish farms. Individual states also developed protocols and regulations to address

12 This case study was prepared by the ISAC Wildlife Health Task Team. However, due to logistical challenges, not all ISAC members had a chance to review it, and thus it was not presented for vote. This annex is a draft document until adopted by ISAC.

the diseases, shaping their specific responses to fit perceived threats to state natural and commercial resources. Currently, there is no means of eradicating these viruses once they have been introduced. Biosecurity measures, fish health testing, and disease surveillance can reduce risks of viral transmission to fish husbandry facilities, as well as the likelihood of introduction into waterways.

SVCV is caused by a viral pathogen that was introduced with imported ornamental common carp (koi) that lacked a required fish health certification prior to importation into the United States. Subsequent to the discovery of SVCV, the United States enacted regulations that require an import permit and a veterinary health certificate for susceptible species. SVC's primary host is the common carp, a species considered an invasive species in its own right. Native fish species, in particular other cyprinids (minnow family) and some centrarchids, have been found to be susceptible to SVCV or could be experimentally infected with the virus (Emmenegger et al. 2016). To avoid interstate movement of the virus, many states now require testing of cultured fish species that could serve as a vector for SVCV before fish can be brought into the state.

VHSV has caused major fish losses in the Great Lakes and affects a wide range of fish species. Escobar et al. (2017) compared the potential devastating impacts of VHSV on native fish species to that of white-nose syndrome in bats and chytrid fungus in amphibians. Not only does VHSV impact wild fish species, it also poses a threat to recreational and commercial fisheries, state and federal stock enhancement programs, and commercial aquaculture. VHSV affects over 80 species of marine and freshwater fish across the Northern Hemisphere (Ito et al. 2016). The specific genotype of VHSV found in the Great Lakes appears to have originated from the Atlantic coast of North America. It might, therefore, be native to one region of the United States, but invasive in regions to which it has been translocated. It is also possible that the virus was first introduced to the Atlantic coast from foreign waters. As with SVCV, many states now require testing for the virus before fish are transported to new waters.

## BIOLOGY

Goodwin (2009) indicated that numerous species have been found to become infected with SVCV, either experimentally or under natural conditions. Initially described in Yugoslavia in 1971 (Fijan et al. 1971), the disease appears to have been present in Europe decades before the initial description. Liu et al. (2004) documented the presence of svcv in China, and noted that its presence in cultured ornamental fish had been suspected since 1998. The virus has also been found in several other Asian countries and the Middle East. Four genogroups of SVCV have been identified, and the strains vary in pathogenicity (Stone et al. 2003). Ahne et al. (2002) and Goodwin (2009) provided excellent reviews on the biology of SVCV and its effect on fish. Briefly, as indicated by its name, SVCV is typically a spring-time disease and is limited to temperatures in the range of 10 to 18 C. Temperatures above 20 C enable fish immune systems to control the disease and it has not been reported from tropical or subtropical regions. The following information is from Petty et al. (2016): External clinical signs are not specific to SVCV, and include swollen abdomen, exophthalmia (pop-eye), skin hemorrhages, and an inflamed or swollen vent. The virus is horizontally transmitted (fish to fish) through water, entering fish through the gills, with transmission also possible through parasites and birds. Vertical transmission (within eggs) has not been ruled out but appears unlikely. Survivors of SVCV infections can become carriers of the disease. SVCV can survive in water for weeks outside of a host.

A new strain of VHSV was isolated from fish collected in 2003 from Lake St. Clair, Michigan (Elsayed et al. 2006). Escobar et al. (2017) stated "the devastating effects of VHSV on a broad range of native fish species is unprecedented." As with SVCV disease, external clinical signs are non-specific, typically consisting of hemorrhagic lesions. The temperature range for the virus is 5 to 20 C. The virus is typically transmitted from fish to fish through water. VHSV can also be experimentally transmitted through predation of infected baitfish (Getchell et al. 2013) and has been found in a leech (Faisal and Schultz 2009) and benthic macroinvertebrates (Faisal and Winters 2011, Throckmorton et al. 2017). VHSV can survive for days to weeks in water, depending upon temperature, water hardness, and other factors, but can also survive on dry surfaces for more than 42–45 days (Oidtmann et al. 2017).

## PATHWAYS OF INTRODUCTION

The first reported case of SVCV in the United States was on a commercial koi farm in 2002 (Goodwin 2002). In the same year, SVCV was found in wild common carp in Wisconsin (Dikkeboom et al. 2004) and in Lake Ontario, Canada, in 2006 (Garver et al. 2007). Outbreaks in Illinois and Lake Ontario appeared genetically linked to the Wisconsin case. Isolates of SVCV found in the U.S. appear to be related to Asian strains (Warg et al. 2007). According to Miller et al. (2007), "It remains unclear, however, whether the viruses isolated in North America were introduced directly from China or entered the country via a third party." As of 2012, SVCV had been found nine times in North America (Phelps et al. 2012). Recently, SVCV has been isolated from Chinese firebelly newts imported into the United States (Ip et al. 2016). The newts had died, but it was not possible to ascertain if SVCV caused the mortality, or more likely, was simply present. Concerns relating to amphibian-fish pathogen host switching were raised by Picco et al. (2010), who found tiger salamanders sold as bait in Arizona were infected with ranaviruses that could be experimentally transmitted to largemouth bass.

VHSV is known to affect marine fish species on the Pacific and Atlantic coasts of North America. Pierce and Stepian (2012) traced the relationships among VHSV strains and concluded that the strain affecting the Great Lakes (IVb) originated from the northwestern Atlantic Ocean and through mutation, adapted to freshwater. Considering the lack of previous findings and the pattern of outbreaks, Elsayed et al. (2006) suggested that "the virus may have been recently introduced into the Great Lakes through one of several potential sources including ballast water or by anadromous or catadromous species that can enter the Great Lakes via the St Lawrence River." The spread of VHSV among the Great Lakes has been attributed to shipping via ballast water discharge (Sieracki et al. 2014) although Bain et al. (2010) found no relation of VHSV in fish and water to shipping and boating sites. Movement of infected fish is another possible pathway. Recently, VHSV was found in walleye broodstock captured from the Maumee River, Ohio, by the Ohio Department of Natural Resources (ODNR). Eggs from the broodstock were taken to a state hatchery for incubation. Fortunately, egg disinfection protocols followed by ODNR personnel have likely prevented transmission of the virus to the hatchery.

## IMPACTS TO WILDLIFE HEALTH

Common carp, a deliberately introduced invasive species, is particularly susceptible to SVCV, especially when young. Losses of wild carp to SVCV disease are generally not a concern to natural resource managers, although there is a commercial fishery for carp as a food-fish. Carp sportfishing and carp fishing tournaments have advocates as well (Cooper 1987). In addition, other cyprinids such as goldfish, bighead carp, silver carp, grass carp, and tench have been found to be susceptible to SVCV. The potential impacts of the virus on native fish species are unknown. The virus was isolated from bluegill and largemouth bass in an Ohio reservoir in 2008 (Phelps et al. 2012). Experimental infections of native fish species, such as pumpkinseed, northern pike, emerald shiner, golden shiner, and fathead minnow, have also been reported. Zebrafish have also been experimentally infected. Possible infection of endangered native minnows has been raised as a concern. Aquatic livestock are also affected by SVCV, either directly or through regulations to control the virus in wildlife. Goldfish and koi are raised commercially and thus SVCV has important implications for producers and importers. Koi fanciers could also be impacted by SVCV, and there are many koi hobbyists across the nation. For example, the Associated Koi Clubs of America alone has 94 member clubs in the United States. Individual show-quality koi can be worth thousands of dollars. To many fish hobbyists, koi are pets and have great sentimental value.

For VHSV, all direct impacts to date have occurred in natural waters in, or close to, the Great Lakes. Numerous fish kills have been attributed to VHSV, and some have been significant. For example, in 2005, some 100 metric tons of Lake Ontario freshwater drum were killed, in addition to smaller numbers of other fish species (Lumsden et al. 2007). According to APHIS (2006), a wide range of fish species can be affected in natural waters:

> "The number of wild fish species found to be susceptible to the North American genotype of the VHS virus is growing, with at least 40 different species (both freshwater and marine) testing positive for the virus. Susceptible fish species are found among the Salmoniformes (salmon, trout), Esociformes (pike), Clupeiformes (herring, anchovy), Gadiformes (cod), Pleuronectiformes (flounders, soles, other flatfishes), Osmeriformes (smelt), Perciformes (perch, drum), Scorpaeniformes (rockfishes, sculpins), Anguilliformes (eels), Cyprinodontiformes (mummichog) and Gasterosteiformes (sticklebacks)."

## ERADICATION AND CONTROL MEASURES

APHIS requires that any imports of fish species (including fertilized eggs and gametes) susceptible to SVCV must be accompanied by an import permit and a veterinary health certificate (71 FR 51429, August 30, 2006). Individual states may require testing for SVCV before live fish of susceptible species can be brought into the state. If SVCV is found on a commercial fish farm, APHIS has the authority to quarantine the farm, and oversee the destruction of fish stocks and the disinfection of ponds. Fish in any surface water supplies used by the farm will be tested to ensure that the virus is not present. Voluntary programs, such as the State of Arkansas Bait and Ornamental Fish Certification Program, require twice-yearly farm-level testing for SVCV (and other pathogens) during the spring and fall seasons when the virus is most likely to be found. Protected water sources, biosecurity measures, and fish health testing greatly reduce the chances of infection of cultured fish as compared to wild fish (Goodwin et al. 2004). Vaccines to protect fish from SVCV are under development, but of course are not an option for wild fish stocks. Reducing common carp biomass in natural waters could reduce the incidence of the disease. Research in Minnesota has shown that clear (unproductive) lakes and high bluegill (egg predator) abundance are major influences in controlling carp abundance (Bajer et al. 2012, 2015). Regulations to control SVCV can have unintended consequences. Zebrafish imports into Canada for scientific purposes have been restricted due to SVCV regulations, causing consternation among the research community (Hanwell et al. 2016).

In 2006, upon identification of VHSV in the Great Lakes, APHIS issued a federal order prohibiting fish shipments among the Great Lake states. This caused major disruptions to commercial aquaculture, natural resource agencies' fisheries programs, and recreational and commercial fishing, and as a result, modifications and testing requirements were developed that replaced the blanket prohibition. The order was followed by an interim rule first published in September 2008 and finally withdrawn in January 2015. State-level regulations developed during this period provided sufficient protection to fish stocks so that federal regulation was no longer needed (80 FR 2285, January 16, 2015). Throckmorton et al. (2015, 2017) documented the decade-long persistence of VHSV in Budd Lake, Michigan, and questioned whether a water body, once infected, could become free of the virus. Ecological niche modeling suggested that VHS, while more common in nearshore areas of the Great Lakes, could still spread to new areas within the lakes (Escobar et al. 2017). The genotype IVb of the VHS virus found in the Great Lakes has continued to mutate and thus may elude host fish defenses, resulting in persistent, long-term losses of native fishes (Stepien et al. 2015). Efforts to control the spread of VHSV have impacted a wide range of individuals and businesses, from anglers to bait dealers to natural resource agencies (e.g., Heck et al. 2013). Phelps et al. (2014) recommended a risk-based management strategy in response to VHSV, differentiating between higher risk watersheds in close proximity to the nearest infected source (Lake Superior) and aquaculture facilities with strict biosecurity protocols and rigorous testing.

## PROJECTED NEEDS FOR ERADICATION

Total eradication of SVCV and VHSV from waters of the United States is not practical. Localized eradication is possible for closed water bodies only by eliminating all aquatic life. For example, earthen fishponds that had held SVCV-infected fish were sterilized using hydrated lime. Costs for indemnification of affected commercial fish producers for the necessary destruction of exposed fish stocks will be site-specific. Fish health-related requirements impose a significant financial burden on farmers and natural resource agencies. A survey of baitfish and sportfish producers found that, while average annual fish health testing costs were $7,250/farm, or 5% of total regulatory costs, labor costs incurred in collecting fish for testing and permitting paperwork added an additional $15,948/farm (van Senten and Engle 2017). Costs to natural resource agency hatcheries operated for fish stock enhancement or restoration will likely be in the same general range, if not higher.

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