ISAC
INVASIVE SPECIES ADVISORY COMMITTEE

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Invasive Species Impacts on Infrastructure

Approved by ISAC on December 6, 2016

EXECUTIVE SUMMARY

Invasive species represent one of the most significant threats to ecosystems, human and animal health, infrastructure, the economy, and cultural resources. Because potentially invasive, non-native species typically enter the United States through ports of entry in urban environments, some of the first observable impacts may be to infrastructure, yet little is known about the economic costs associated with these impacts to the "built" environment. In addition, federal agencies currently lack the authority necessary to effectively prevent, eradicate, and control invasive species that impact the human-built environment. This lack of authority prevents rapid response to some of the most damaging invasive species and also limits the ability of agencies to prioritize and allocate the resources necessary to control invasive species that threaten infrastructure (2016–2018 NISC Management Plan).

In this report we respond to two Action Items in the 2016–2018 Management Plan:

1. Compile case studies of the invasive species impacts on infrastructure in the United States and make them available through the NISC website or other public domain (Action 4.2.1) and
2. Taking into consideration the output of Action 4.2.1, develop guidance that enables Federal agencies to take the necessary action to prevent, eradicate, and control non-native species that harm or have the potential to harm infrastructure within the United States and its overseas territories (Action 4.2.2).

To that end, this report defines what constitutes infrastructure and the relationship to federal agency authorities, goes on to describes four types of infrastructure including power, water, transportation, and housing systems, and then documents the infrastructure and non-infrastructure impacts of five representative invasive species through detailed case studies. We conclude the report with a set of recommendations to help federal agencies take the necessary action to prevent, eradicate, and control invasive species that have the potential to harm infrastructure within the United States.

INTRODUCTION

Invasive species affect multiple sectors of society. Congress and state legislatures are concerned that the American infrastructure sector is crumbling. Invasive species are accelerating the degradation of that infrastructure in every region of the

Agency/Infrastructure Category	Power	Water	Transportation	Housing
Department of Agriculture		✓		✓
Department of Commerce		✓		✓
Department of Defense	✓	✓	✓	✓
Department Energy	✓			
Department of Health and Human Services				✓
Department of Homeland Security	✓	✓	✓	
Department of Housing and Urban Development				✓
Department of the Interior	✓	✓	✓	✓
Department of Transportation			✓	
Environmental Protection Agency		✓	✓	
National Aeronautics and Space Administration	✓			

Table 1. Select Federal Agencies with Infrastructure that could be affected by invasive species.

country, creating tens of billions of dollars in unfunded liabilities for state and local governments.

For purposes of this paper we define infrastructure as systems of manmade physical structures. Our analysis summarizes the impact of invasive species on four systems of infrastructure: electric power, water, transportation, and housing. There are dozens of invasive species affecting each of these infrastructure systems, and several of them affect multiple systems simultaneously. Some regions of the country may presently be bearing the greater share of the national burden from damage to infrastructure from particular invasive species, but that is only because the invasive species in question have not yet had the time or opportunity to spread to other regions. The other as yet uninfected regions are just as vulnerable and face large potential costs that can still be avoided through effective regulation, partnerships, and targeted research.

This paper describes each system of infrastructure in turn, provides an overview of some of the many invasive species affecting that system, and presents in-depth case studies of five particular species. We briefly note any public health and ecological risks associated with the case study invasive species, but focus primarily on infrastructure impacts. We then provide conclusions and make detailed recommendations for what the federal government can do to reduce the risks to infrastructure from invasive species. Multiple federal agencies and their stakeholders are affected by infrastructure problems caused by invasive species, as summarized in Table 1.

TYPES OF INFRASTRUCTURE

Power Systems

We define the power system infrastructure as the facilities that generate, transmit, and distribute electric energy. This includes generation from renewable, fossil, hydropower, and nuclear forms of energy. The system also includes dams, power plants, interstate and intrastate transmission lines that transport electric energy from generating stations and distribution lines that deliver electricity to individual end-point retail customers. There are many invasive species that directly cause power outages or whose control results in higher maintenance costs that in turn results in higher electric rates for consumers. These include brown tree snakes that cause electric outages, zebra and quagga mussels and aquatic weeds that foul dams and power plant cooling systems, crazy ants eating home electric connections, monk parakeets, and invasive insects killing trees that then fall and snap transmissions lines.

Water Systems

We define the water system as the facilities that treat drinking water and wastewater, control floodwaters, divert stormwater, impound water for a variety of purposes, and divert or convey water to agricultural and municipal users. Among the many invasive species affecting water systems are: tamarisk/saltcedar, which deplete scarce water supplies in the drought-stricken West; zebra and quagga mussels, which clog any type of water pipe; aquatic weeds, which clog water conveyances; feral hogs, which put holes in levees; and nutria, iguanas, and armored catfish, which burrow into levees and weaken them.

Transportation Systems

We define the transportation infrastructure system as the manmade facilities that include highways, railroads, waterways, ports and airways. These modes provide mobility for people and goods to safely move from one place to another and unintentionally provide pathways for the human-facilitated rapid movement of invasive species. In addition, invasive species cause direct damage to transportation facilities: roads, rails, navigation facilities, and airports. These include zebra and quagga mussels and aquatic weeds that foul navigation locks and port facilities; giant cane that backs up behind waterways during flash floods and so blows out culverts and bridges; and kochia which causes highway accidents.

Housing Systems

We define housing infrastructure as the manmade facilities that provide habitation for human beings in America. This includes single family and multi-family dwellings. Invasive species pose a variety of threats to the American housing stock. These threats include cheatgrass and buffelgrass, which threaten homes with destruction from wildfire; giant African land snails, which eat concrete and stucco construction materials; crazy ants that eat the insulation on electrical connections found in homes; Formosan termites, which eat wooden structures; English ivy, which tears the grout from between masonry; and emerald ash borers, which kill ash trees that may damage residential property when the stricken trees fall.

IMPACTS ON INFRASTRUCTURE

Myocastor coypus (Nutria)

The nutria (*Myocastor coypus*) is a large, semi-aquatic rodent native to South America. Nutria were originally introduced to the United States in 1889 for the benefit of the fur-farming industry (Jojola et al. 2005). Nutria negatively impact infrastructure in two ways: through herbivory which leads to habitat destruction and through their burrowing behavior (LeBlanc 1994). Nutria burrows can weaken flood control levees that protect low-lying areas as well as roadbeds, stream banks, dams, and dikes under heavy weight (LeBlanc 1994). In Louisiana, nutria commonly undermine and break through water-retaining levees in flooded fields used for rice and crawfish production (LeBlanc 1994).

Nylanderia fulva (Tawny Crazy Ant)

The Tawny crazy ant, called “crazy” for how they rapidly and randomly move about, are medium-small, 2.6–3 mm long, monomorphic, golden-brown to reddish-brown ants that have a smooth and glossy body surface covered with dense hairs. The Tawny crazy ant was first discovered near Houston, Texas in 2002 by Tom Rasberry, a pest control man. Originally named the Rasberry crazy ant in his honor, it quickly turned into a problem for local residents and businesses as it infiltrated homes and destroyed electrical work. Even NASA called on Rasberry and others in order to eradicate the ant from electrical wiring at NASA facilities. In areas infested by the Rasberry crazy ant, large numbers of ants have accumulated in electrical equipment, causing short circuits and equipment failure and clogging switching mechanisms**.**

Coptotermes formosanus **(Formosan termite)**

Coptotermes formosanus (Shiraki 1909), currently one of the most destructive pests in the United States, is a social insect species in the termite family (Insecta: Isoptera: Rhinotermitidae) (Froggart 1897; Integrated Taxonomic Information System 2016; Invasive Species Specialist Group 2016). Formosan termites can form large colonies comprised of several million individuals that forage up to 100 m, mostly in urban areas (Henderson 2015). *Coptotermes formosanus* is estimated to cost consumers over $1 billion annually for preventative and remedial treatment and to repair damage caused by this insect (Lax and Osbrink 2003). The Formosan termites readily enter through "expansion joints, cracks and utility conduits" under slabs on the ground (Su and Scheffrahn 2016). On some occasions Formosan subterranean termites can form colonies that are not connected to the ground, establishing themselves on flat rooftops and in high-rise buildings (Su and Scheffrahn 2016). A colony of 200,000 Formosan termites can consume up to 12 pounds of cellulose per year making them one of the most significant threats to the preservation of historic structures in the United States (Jones et al. 2014). In addition to houses, Formosan termites can also infest railroad ties, wharves, telephone poles, fence posts, furniture, and books (Morgan et al. 2016). According to CABI's Compendium of Invasive Species, USDA initiated an eradication program centered in the French Quarter of New Orleans, spending over $70,000,000 on studies to control the termite species (Henderson 2016).

Arundo donax **(Giant Reed)**

Giant reed is a tall, perennial grass that can grow to over 20 feet in height. Its fleshy, creeping rootstocks form compact masses from which tough, fibrous roots emerge that penetrate deeply into the soil. Leaves are elongate, 1–2 inches wide and a foot long. The flowers are borne in 2-foot long, dense, plume-like panicles during August and September. Giant reed chokes riversides and stream channels, crowds out native plants, interferes with flood control, increases fire potential, and reduces habitat for wildlife, including the least Bell's vireo, a federally endangered bird. The long, fibrous, interconnecting root mats of giant reed form a framework for debris dams behind bridges, culverts, and other structures that lead to damage. Giant reed can float miles downstream where root and stem fragments may take root and initiate new infestations. Due to its rapid growth rate and vegetative reproduction, it is able to quickly invade new areas and form pure stands at the expense of other species. Once established, giant reed has the ability to outcompete and completely suppress native vegetation.

Dreissena rostriformis bugensis **and** ***Dreissena polymorpha*** **(Dreissenid Mussels)**

The Dreissenidae are a family of small freshwater mussels. These filter-feeding bivalves have a free-floating immature stage and attach to hard surfaces using a byssus. The *dreissenid* mussels discussed here are the quagga mussel (*Dreissena rostriformis bugensis*) and the zebra mussel (*Dreissena polymorpha*). Dreissenid mussels grow on a variety of infrastructure systems, including water intake pipes for drinking water, irrigation, and power plants. They also attach to locks, the faces and interiors of dams and canal systems, greatly impacting operation and maintenance costs. With continual attachment, the mussels can increase corrosion rates of steel and concrete (USGS 2016), leaving equipment and infrastructure vulnerable to failure. Additionally, the mussels grow on navigational buoys, docks, and hulls of boats and ships—increasing drag, affecting steering, and clogging engine intakes—all of which can lead to overheating and engine malfunctions.

RECOMMENDATIONS

Invasive species impact American infrastructure and therefore affect the programs of federal agencies with infrastructure missions. However, the impact of invasive species on those agency missions is not well documented, and so those agencies are not in a position to systematically mitigate their impact to infrastructure. The ISAC therefore recommends:

1. NISC should work with relevant federal agencies to help them assess the physical and economic impacts of invasive species on the infrastructure projects that they manage directly or support through federal funding. Documentation should include baseline inventories, infrastructure risk assessment, long-term strategies, budgetary needs and measures of success.
2. Given that it is difficult for agencies to quantify the costs of invasive species infrastructure impacts because those costs are often included in overall maintenance and repair budgets, ISAC recommends that NISC work with relevant federal agencies to quantify the actual cost of invasive species management to federally owned or supported infrastructure.
3. For existing infrastructure, ISAC recommends to NISC that relevant federal agencies establish mechanisms for funding early detection and rapid response to minimize the impact and the economic burden of invasive species management.
4. In the case of new construction or major renovation to existing infrastructure, ISAC recommends that NISC help

agencies adopt innovative construction practices that will prevent future impact from invasive species.

APPENDIX 1
Myocaster coypus (NUTRIA)

The nutria (*Myocastor coypus*) is a large, semi-aquatic rodent native to South America. Nutria were originally brought to the United States in 1889 for the benefit of the fur-farming industry (Jojola et al. 2005). Thus, nutria introduction was intentional and originally viewed as providing economic benefit. Nutria were subsequently introduced into a number of states for both fur production and vegetation control. When the nutria fur market collapsed in the 1940s, thousands were released into the wild from failed nutria farms (Jojola et al. 2005). Nutria have been documented in thirty states and are currently established in at least fifteen States (USGS 2016).

The nutria somewhat resembles a very large rat, or a beaver with a small tail. Adults are typically 40–60 cm (16–24 in) in body length, and 4–9 kg (8.8–19.8 lb) in weight with a 30–45 cm (12–18 in) tail (LeBlanc 1994). They are very prolific with females reaching sexual maturity as early as three months, gestation lasts 130 days, and litter size may be as large as thirteen. Nutria are born fully furred and with open eyes; they can eat vegetation within hours of birth. In some conditions a female can become pregnant three times within a year (LeBlanc 1994).

Nutria are voracious herbivores that eat a wide variety of wetland vegetation. An individual consumes about twenty-five percent of its body weight daily and feeds year-round. They eat the base of the above-ground stems of plants and often will dig through the organic soil for roots and rhizomes. Nutria are most common in freshwater marshes, but also inhabit brackish marshes and rarely salt marshes.

Nutria are efficient diggers and frequently dig burrows into the banks of the waterways they inhabit. Burrows are most commonly dug into banks that have forty-five degree to ninety degree slopes and can range in size and complexity with some extending as much as forty-five meters with branches and multiple entrances (Baroch et al. 2002).

Infrastructure Impacts

Nutria negatively impact infrastructure in two ways: through herbivory, which leads to habitat destruction and through their burrowing behavior which leads to the destabilization of water retention and flood control levees, canal, and ditch banks and the foundations of roadways and structures (LeBlanc 1994).

It is well documented that nutria have caused widespread ecosystem changes along the Gulf Coast and the Chesapeake Bay in Maryland (USDA-APHIS Wildlife Services 2010). Through a combination of vegetation loss from herbivory and changes to the associated soils, marshland damage can be permanent. This increases the vulnerability of adjacent upland sites to erosion and flooding during storms (USDA-APHIS Wildlife Services 2010). Intact salt marshes provide significant benefits to inland areas through wave attenuation, shoreline stabilization, and floodwater attenuation (Shepard et al. 2011). As nutria alter these marshes, ever greater infrastructure impacts from flood events may be expected.

Significant nutria-related infrastructure damage comes from their burrowing behavior. Nutria burrows can weaken flood control levees that protect low-lying areas as well as roadbeds, stream banks, dams, and dikes under heavy weight (LeBlanc 1994). In Louisiana, nutria commonly undermine and break through water-retaining levees in flooded fields used for rice and crawfish production (LeBlanc 1994).

Measures Taken

Significant control programs for nutria have been conducted in most areas where they have become established. Preventative strategies such as exclusion have proven effective in small areas, but large scale exclusion efforts are typically not feasible. Relocation is not a control option, so lethal methods are frequently employed. Trapping and shooting are effective controls, and the toxicant Zinc phosphide is effective when used with bait (LeBlanc 1994).

Commercial harvest is an effective control, but low pelt prices have led to most trappers exiting the market (Jordan et al. 2010). Consequently, several efforts have been made to provide incentives to increase annual harvests. For example, in Louisiana the Coastwide Nutria Control Program has paid harvest bounties to individuals since 2002. In 2010, 445,963 nutria were harvested which resulted in the payment of $2,229,815 in incentives (Jordan et al. 2010). This harvest level seems to be beneficial as the number of acres of nutria damage were reduced by fifty-eight percent from the previous year (Jordan et al. 2010).

Commercial harvest for utilization of the animal is occurring at low levels. However, companies are looking at alternative uses of the meat. Recently, a Louisiana company has begun marketing dog treats made from nutria.

Economic Considerations

With the collapse of the fur industry in the late 1980s the nutria population exploded. Both the burrowing behavior of the nutria and the destruction of coastal vegetation have important economic infrastructure impacts. The weakening of levees and canals that then must be repaired can be illustrated in Jefferson Parish, Louisiana. The Parish has 280 miles of drainage canals. In the early 1990s nutria caused about $8 million of damages on fourteen percent of the canals. One response to this would have been to line the canal with concrete, but in the 1990s this would have cost $15 million per linear mile. Reducing the number of nutria was potentially a more cost effective approach. Louisiana undertook a program to reduce the number of nutria primarily because of the loss of coastal wetlands and vegetative protection from extreme weather events. By the late 1990s over 100,000 acres of Louisiana coastline were being damaged by nutria. The removal of the vegetation by nutria, often including the root material, resulted in erosion and lowering of coastlines as well as elimination of vegetative barriers. Louisiana began its Coastwide

Nutria Control Program in 2002 which provided a bounty for nutria, now at $5 per tail. This has resulted in a reduction of 4,000 to 6,000 acres of annual damage since 2012. In recent years the reduction of animals has been between 300,000 and 450,000 annually at a cost of approximately $1.2 million to $2.3 million in bounty payments per year. A study that looked at wind damage reduction value for the Louisiana coast estimated it at $20 per acre at a three percent discount rate. Flood damages to low-lying coastal areas would be considerably more than this wind damage and the value of coastal vegetative protection was thus much more. This value of protection would also increase where there was more valuable infrastructure inshore.

Another state that has had an extensive nutria control program is Maryland. Here the damage from wetland and habitat destruction by nutria was estimated not for infrastructure but for commercial and sport fishing, hunting, and wildlife watching. Damages were based on estimates of future marsh and wetland loss as these accumulated over time and deteriorated the resource base. Estimated annual damages totaled tens of millions of dollars in future years if nutria remained unchecked. Maryland began a three-year pilot program in 1998 with a million dollars a year of federal appropriations. In 2003, four million dollars a year was appropriated for five years for nutria eradication, and efforts have continued. Large areas of the targeted coast now appear to be largely nutria-free. While there is a great deal of information on damages from nutria and the costs of their control or possible eradication, the information is not necessary parallel in time and space. It should be possible to pull existing information together a bit more coherently and get a better picture. More work needs to be done, particularly on issues like storm surge damage and the protection value of wetlands and marshes—especially in the context of risk from possible climate change.

APPENDIX 2
Nylanderia fulva (TAWNY CRAZY ANT)

The Rasberry crazy ant, called "crazy" for how they rapidly and randomly move about, are medium-small, 2.6–3 mm long, monomorphic, golden-brown to reddish-brown ants that have a smooth and glossy body surface covered with dense hairs. Worker ants have long legs and antennae, and their bodies have numerous, long, coarse hairs. Their heads are shiny, sparsely pubescent, and subcordate. The antenna have twelve segments with no club, and their antennal scape is nearly twice the width of the head. After feeding, the ant's gaster (portion of the rear abdomen) will appear to be striped due to stretching of the light-colored membrane connecting the segments of the gaster. Its thorax is densely pubescent with long, abundant light-brown hairs. There is a small circle of hairs, called the acidopore, present at the tip of the abdomen, as opposed to the typical stinger found in most ants—a characteristic of formicine ants. The Rasberry crazy ant is a social insect that is usually found in extremely large numbers and lives in large colonies or groups of colonies that seem to be indistinguishable from one another. Aside from the worker ants, the reproductive males and females of the Rasberry crazy ant are similar in color but are larger and possess wings. Queens are larger still and are responsible for producing the millions of larvae within the colony.

The Rasberry crazy ant was first discovered near Houston, Texas in 2002 by Tom Rasberry, a pest control man who has the ant named in his honor. The ant quickly turned into a problem for local residents and businesses as it infiltrated homes and destroyed electrical work. Even NASA called on Rasberry and others in order to eradicate the ant from electrical wiring at NASA facilities. The ant is believed to have traveled to the U.S. aboard a commercial ship, probably from South America where the ants are indigenous. Their exact means of entry are unknown, but precautions are being taken to avoid the spread of Rasberry crazy ants.

Rasberry crazy ants eat almost anything; they are omnivorous. Worker ants commonly "tend" sucking hemipterous insects such as aphids, scale insects, whiteflies, mealybugs, and others that excrete a sugary (carbohydrate) liquid called "honeydew" extracted from host plants when stimulated by the ants. Worker ants are also attracted to sweet parts of plants including nectaries and damaged or over-ripe fruit.

The Rasberry crazy ant has only been found in the state of Texas—near Pasadena—since 2002. High densities of these ants have been documented in localized spot infestations in southeast Houston in Harris County, including Houston, Pasadena, Deer Park, Friendswood, San Jacinto Port, Pearland, Seabrook, and La Porte. Additional localized infestations have also been confirmed from areas in Bexar, Brazoria, Cameron, Fort Bend, Chambers, Galveston, Hardin, Harris, Hidalgo, Jefferson, Jim Hogg, Liberty, Montgomery, Nueces, Orange, Walker, and Wharton counties. New infestations are suspected beyond these areas. However, sample identifications have not been confirmed. This ant has the potential to spread well beyond the current range in coastal Texas. This is a semi-tropical ant, and potential northern distribution will be limited by cooler weather conditions.

Non-Infrastructure Impacts

While the exact impact of the Rasberry crazy ant on the local ecology is unknown, a related species in this genus, *Nylanderia fulva*, has been a serious pest in rural and urban areas of Colombia and South America. In this case, they reportedly displaced all other ant species and caused small livestock (e.g., chickens) to die of asphyxia. Larger animals, such as cattle, have been attacked around the eyes, nasal fossae, and hooves. Further, wildlife, such as nesting songbirds, are irritated by Rasberry crazy ants. Masses of crazy ants covering the ground and trees likely affect ground and tree-nesting birds and other small animals and cause wildlife to move out of the area. These ants are even displacing red imported fire ants in areas of heavy infestation. Ironically, after experiencing the Rasberry crazy ant, most residents prefer the fire ant.

Infrastructure Impacts

In areas infested by the Rasberry crazy ant, large numbers of ants have accumulated in electrical equipment, causing short circuits and equipment failure and clogging switching mechanisms. These ants are likely to be transported through movement of almost any infested container or material. Thus, movement of garbage, yard debris, bags, loads of compost, potted plants, and bales of hay can transport these ant colonies by truck, train, and airplane**.** Rasberry crazy ants do not have stingers. In place of a stinger, worker ants possess an acidopore at the end of the abdomen, which can excrete chemicals for defense or attack. They are capable of biting, and when bitten, they cause a relatively sharp pain that quickly fades.

Measures Taken

Many of the typical control tactics for other ants do not provide adequate control of the Rasberry crazy ant. Because colonies predominantly nest outdoors, reliance on indoor treatments to control these ants foraging inside structures are not effective. Rasberry crazy ant workers are not attracted to most bait products, and the one known product they are attracted to (Whitmire Advance Carpenter Ant Bait formulation containing abamectin) does not offer enough control. Effective products involved with the treatments are not readily available to the consumer.

Economic Aspects

There is no good estimate of economic damages, so individual instances provide the only data so far with little sense of the extent of such cases. There is confusion with damage from fire ants, which has been better documented. Much of the available information on crazy ants is from news and popular sources. One of the major damages attributed to this insect is damage to electrical equipment, implying some attraction by the ant to electricity. Crazy ants will pack electrical boxes and short out circuits. There are individual reports of shorted computer systems and electronic controls with damages in the ten to fifteen thousand dollar range. At the home scale they have been responsible for equipment failures (like air conditioners) and fuse box failures. Damages to electrical equipment of $146.5 million have been attributed to crazy ants, but the actual study determining this amount was for fire ants. Part of the damage potential relates to the large size of their interconnected colonies and the large number of queens per colony. They spread easily and are prolific. They also infiltrate existing available cavities for nests, be it electrical boxes, pipes, etc., rather than building nests like fire ants. While they do not bite, they can cover an individual's skin and be extremely irritating to pets, humans, and other living creatures. Control costs are high because of the dispersal and because they do not respond to many common pesticides. Maintaining a one-acre barrier around a home in an infested area can cost in excess of two thousand dollars a year. Control methods do not appear to have been determined, so that determining the potential cost of control, beyond something like home level instances, is not possible. A first step might be attempting to determine best control practices and then assess such costs.

APPENDIX 3
Coptotermes formosanus (FORMOSAN TERMITE)

Coptotermes formosanus (Shiraki 1909), currently one of the most destructive pests in the United States, is a social insect species in the termite family (Insecta: Isoptera: Rhinotermitidae) (Froggart 1897; ITIS 2016; ISSG 2016). An insect species indigenous to China, *C. formosanus* arrived in Hawaii in the early years of the 20th century establishing a presence in Charleston, South Carolina by 1957 (Su 2003; USDA National Agricultural Library 2016). Formosan termites can form large colonies comprised of several million individuals that forage up to 100 m, mostly in urban areas (Henderson 2016). Formosan termite workers are difficult to identify as *C. formosanus*; the soldiers and alates, however, look different from native subterranean species and are easy to identify (Invasive Species Specialist Group 2016).

Coptotermes formosanus competes with native termite species and can cause significant damage to native tree species such as Acer rubrum (Henderson 2016). There is the potential for Formosan subterranean termites (*Coptotermes formosanus*) and Asian subterranean termites (*C. gestroi*), both of which are invasive in the United States, to hybridize (Chouvenc et al. 2013).

Infrastructure Impacts

Coptotermes formosanus is estimated to cost consumers over $1 billion annually for preventative and remedial treatment and to repair damage caused by this insect (Lax and Osbrink 2003). The Formosan termites readily enter through "expansion joints, cracks and utility conduits" under slabs on the ground (Su & Scheffrahn 2016). On some occasions Formosan subterranean termite can form colonies that are not connected to the ground, establishing themselves on flat rooftops and in high-rise buildings (Su and Scheffrahn 2016). A colony of 200,000 Formosan termites can consume up to 12 pounds of cellulose per year making them one of the most significant threats to the preservation of historic structures in the United States (Jones et al. 2014). In addition to houses, Formosan termites can also infest railroad ties, wharves, telephone poles, fence posts, furniture, and books (Morgan et al. 2016). According to CABI's Compendium of Invasive Species, USDA initiated an eradication program centered in the French Quarter of New Orleans, spending over $70,000,000 on studies to control the termite species (Henderson 2016).

APPENDIX 4
Arundo donax (GIANT REED)

Giant reed is a tall, perennial grass that can grow to over 20 feet in height. Its fleshy, creeping rootstocks form compact masses from which tough, fibrous roots emerge that penetrate deeply into the soil. Leaves are elongate, 1–2 inches wide and a foot long. The flowers are borne in 2-foot long, dense, plume-like panicles during August and September. Introduced from western Asia, northern Africa, and southern Europe in the early 1800s, giant reed was probably first introduced into the United States at Los Angeles, California in the early 1800s. Since then, it has become widely dispersed into all of the subtropical and warm temperate areas of the world, mostly through intentional human introductions. Today, giant reed is widely planted throughout the warmer areas of the United States as an ornamental and in the Southwest, where it is used along ditches for erosion control. Giant Reed tolerates a wide range of soil types and moisture, but prefers riverine or similar habitats that can include: irrigation channels, rivers/streams, coastal dunes, managed forests or grasslands, railways and roadsides, natural forests and grasslands. It is also found on riverbanks, wetlands, agricultural land, and coastal areas.

Non-Infrastructure Impacts

Giant reed outcompetes native habitat, warms water for aquatic wildlife and fisheries, exacerbates flooding, replaces native wildlife habitat, reduces biodiversity, diminishes groundwater availability, and alters water flow during storm events. Giant reed reduces native vegetation and nesting sites for endangered species, like the least Bell's vireo, willow flycatcher and yellow cuckoo. It shelters Norway rats, which predate on other native species. Under competition, the natural complex food web becomes simplified and fewer species survive in its presence. *Arundo donax* has proven extremely flammable in an already fire-prone region of the United States. Arundo doubles the fuel load, spreads rapidly and regenerates even greater quantities and monocultures available to future wildfires. Isolating costs to infrastructure is not known. We do not know if Arundo fires have led to loss of human life, but because regional trafficking and homelessness lead to the use of *Arundo donax* as shelter, the threat exists.

Infrastructure Impacts

The long, fibrous, interconnecting root mats of giant reed form a framework for debris dams behind bridges, culverts, and other structures that lead to damage. Giant reed can float miles downstream where root and stem fragments may take root and initiate new infestations. Due to its rapid growth rate and vegetative reproduction, it is able to quickly invade new areas and form pure stands at the expense of other species. Once established, giant reed has the ability to outcompete and completely suppress native vegetation.

Measures Taken

Areas infested with giant reed are best restored through chemical means. Mechanical control (e.g., repeated mowing) may be somewhat effective, but if small fragments of root are left in the soil, they may lead to reestablishment. Systemic herbicides, such as glyphosate (e.g., Rodeo), may be applied clumps of giant reed, after flowering, either as a cut stump treatment or as a foliar spray. Prescribed burning, either alone or combined with herbicide applications, may be effective if conducted after flowering. Once giant reed has been reduced sufficiently, native plants may be seeded or transplanted at the treated site. With respect to biological control, a chloropid fly has been used in France and parallel studies of North American natural enemies are underway including a field releases of a wasp, *Tetramesa romana*, in 2009 and the Arundo scale insect (*Rhizaspidiotus donacis*) in 2010.

Economic Aspects

Arundo donax can cause economic damage in a number of different instances. Many of those relate to its waterway habitat. A study for the Rio Grande Basin looks at the economics of biological *Arundo donax* control. The plant is a large water consumer in canals and in riparian habitat like the Rio Grande. By 2008 it had already invaded several thousand acres of this region. A plant can consume up to 4 acre feet of water a year. In areas where water is scarce and/or expensive it becomes economic to control the plant for the value of the water saved (Seawright et al. 2009). Taking the value of the water saved by control against the cost of the biological control, the benefit cost ratio indicated over $4 of benefits for every dollar of public investment in control. The per-unit cost of water saved was just over $44 an acre foot. This is a competitive water price in an area of water scarcity even for agriculture as the residuary claimant. A similar study was done for California in selected watersheds (Giessow et al. 2011). They estimated a cost of $25,000 per acre for control. In addition to the value of the water saved, benefits were also considered for reduced sediment trapping and reduced flood damage. The average cost benefit ratio was approximately 2 to 1. In some watersheds it was as high as the Rio Grande study.

APPENDIX 5
Dreissena rostriformis bugensis and *Dreissena polymorpha* (DREISSENID MUSSELS)

The Dreissenidae are a family of small freshwater mussels. These filter-feeding bivalves have a free-floating immature stage and attach to hard surfaces using a byssus. The *dreissenid* mussels discussed here are the quagga mussel (*Dreissena rostriformis bugensis*) and the zebra mussel (*Dreissena polymorpha*). These two closely related species are native to eastern Europe and western Russia. They are both also highly invasive where they have been introduced to North American waters.

History

Dreissenid mussels are thought to have been introduced to North America via the ballast of commercial ships traversing the St. Lawrence Seaway. Zebra mussels are thought to be the first dreissenid mussel introduced to North America. The organisms were first found attached to the surfaces of rocks, piers, and other underwater structures in Lake St. Clair in 1988. It is unclear how long the species had been in the Great Lakes before detection at Lake St. Clair, which connects to lakes Huron and Erie. The closely related quagga mussel was first detected in Lake Erie in 1989. It was not immediately understood that the two species were distinct because they so closely resemble one another.

By 1989, dreissenid mussels had spread to Lake Ontario, the St. Lawrence River, and, by the early 1990s, were found throughout the Great Lakes and in major eastern North American river systems with connections to the Great Lakes via the Chicago Sanitary and Ship Canal. This includes the Ohio, the Mississippi, and the Missouri rivers. Initial containment efforts for dreissenid mussels were deficient in the early 1990s, largely due to a failure to recognize the significance of the discoveries and a lack of understanding of potential economic and environmental consequences.

In addition to passive movement of mature and immature stages of the mussels in flowing water, dreissenid mussels use byssal threads to attach to equipment, boats, trailers, docks, and anchors, essentially "hitchhiking" between unconnected waterbodies. This pathway has intensified the rate of spread throughout North America. The mussels were discovered for the first time in the western United States in 2007 at Lake Mead, Nevada. In the nine years since this discovery, dreissenid mussels have quickly spread to waterbodies in every western state except Idaho, Washington, Oregon, Wyoming, and Montana.

U. S. Habitat

Dreissenid mussels inhabit freshwater lakes, rivers, ponds, quarries, and reservoirs. The preferred depth varies depending on water temperature. The mussels are not generally found near the shore or in shallow water due to warmer temperatures and wave action (USGS 2016). Zebra mussels tend to prefer hard surfaces, while quagga mussels can inhabit both hard and soft substrates up to depths of 130 meters (USGS 2016).

Distribution

Quagga mussels are thought to have been introduced to North America more recently than zebra mussels. This may indicate that quagga mussels are still in the process of expanding their range. Dreissenid mussel species are now well-established in the Great Lakes, the Mississippi, Hudson, St. Lawrence, Ohio, Cumberland, Missouri, Tennessee, Arkansas, Huron, Red, and Colorado rivers. New discoveries have also been made in additional lakes in Minnesota, Utah, and Lake Winnipeg in Manitoba.

Following the western North American Lake Mead invasion in early 2007, dreissenid mussels quickly spread to connected lakes and reservoirs in Arizona and southern California waters (via the California Aqueduct and Central Arizona Project). These mussels have also now invaded many other hydrologically disconnected water bodies in the western states of Nevada, Arizona, California, New Mexico, Colorado, Texas, and Utah. The states of Idaho, Oregon, Washington, Montana, Wyoming, Alaska, and Hawaii are the only western states uninvaded by the mussels. The Columbia River Basin remains virtually the only un-infested basin in the western United States.

Non-Infrastructure Impacts

These biofouling species have had strong negative economic consequences where they have been introduced. They also have ecosystem-level impacts, which include direct competition with native taxa (Birnbaum 2006). Dreissenid mussels are filter feeders, removing phytoplankton and suspended particles from the water column. Removing phytoplankton decreases available food sources for zooplankton, severely impacting the aquatic food web (USGS 2016). The USGS cites impacts associated with the filtration of water, including increases in water transparency, decreases in chlorophyll concentrations, and accumulation of pseudofeces (Claxton et al. 1998). Increased water clarity increases light penetration and causes increases in aquatic plant growth. When pseudofeces accumulates, it creates a foul environment; as oxygen is used up, the water pH becomes acidic and toxic. The mussels also bioaccumulate pollutants, which can be passed up the food chain, increasing wildlife exposure to organic pollutants (Snyder et al. 1997). The mussel shells are sharp which forces people to wear shoes when walking on infested shores.

Infrastructure Impacts

Dreissenid mussels grow on a variety of infrastructure systems, including water intake pipes for drinking water, irrigation, and power plants. They also attach to locks, the faces and interiors of dams and canal systems, greatly impacting operation and maintenance costs. With continual attachment, the mussels can increase corrosion rates of steel and concrete (USGS 2016), leaving equipment and infrastructure vulnerable to failure. Additionally, the mussels grow on navigational buoys, docks, and hulls of boats and ships—increasing drag, affecting steering, and clogging engine intakes—all of which can lead to overheating and engine malfunctions.

Congressional researchers estimated that the Great Lakes infestation has cost the power industry alone $3.1 billion between 1993 and 1999, with a total economic impact on industries, businesses, and communities of more than $5 billion (Western Regional Panel on Aquatic Nuisance Species 2009). It has been estimated that it costs over $500 million per year to manage mussels at power plants, water systems, and industrial complexes, and on boats and docks in the Great Lakes (Center for Invasive Species Research). A recent estimate by the U. S. Army Corps of Engineers indicates that quagga mussels could cause annual loses of $22 million to the Lake Tahoe region (U.S. Army Corps of Engineers 2009). The report details potential damage to tourism, reduced property values, and increased maintenance costs. Connelly (2007) estimated total economic costs of $267 million for electric-generation and water-treatment facilities in the entire United States from 1989 through 2004.

There is a wide range in the forecast of potential economic costs. Warziniack (2006) estimates "the expected loss to households in the Columbia Basin will be about $1.94 million annually" if introduced. The state of Idaho conducted an analysis of potential impacts of these species to Idaho's environment and industries. The Idaho estimate (Ferriter 2015) includes costs due to direct and indirect impacts on infrastructure and facilities that use surface water. The following categories of infrastructure were examined:

HYDRO POWER

Estimates were based on a Bonneville Power Administration-commissioned study that examined the estimated hydropower maintenance costs associated with zebra mussels. Costs associated with Asian clam control at Bonneville Dam First Powerhouse and a survey of zebra mussel mitigation costs at other hydropower generation facilities in North America were used. The study estimated the costs for installing sodium hypochlorite systems and applying antifouling paint to thirteen federal hydroelectric projects in the Columbia River Basin. The Idaho estimate was based on the BPA average cost per project ($1.8 million) for the twenty-six hydropower dams in Idaho (Phillips et al. 2005).

OTHER DAMS

Other dams include water impoundment structures not associated with power generation. These structures would expect to incur annual maintenance costs associated with mussel fouling of pipes and structures. Estimates based on figures from O'Neil (1997) for navigational lock structures ($1,700 per structure) applied to eighty-six structures in the state yields an estimate of approximately $150,000 for Idaho.

DRINKING WATER INTAKES

Estimates included drinking water facilities that draw surface water for municipal or public drinking water use. Mussels foul intake piping and water processing infrastructure, increasing maintenance costs and degrading water flavor due to mussel waste and decomposition in water lines. Private single-family home water intakes for drinking and irrigation are not included in this estimate. Estimates of $4.2 million annually are based on O'Neill (1997) figures from water treatment facilities ($42,000 per facility) applied to 100 facilities in Idaho.

GOLF COURSES

Golf courses are at risk for additional maintenance costs for irrigation systems. Fouling of pipes and pumps and clogged sprinklers are projected to increase operating expenses. Estimates based on O'Neill (1997) costs from golf courses ($150 per facility) were applied to 114 Idaho courses.

BOATING FACILITIES

Boating facilities included Idaho marinas, docks, and boat launches. Increased cost estimates are based on maintenance associated with dock and boat launch fouling. Estimates of $285,000 annually based on O'Neill (1997) figures from marinas ($750 per facility) were applied to 380 Idaho facilities.

FISH HATCHERIES AND AQUACULTURE

Hatcheries and aquaculture facilities are vulnerable to dreissenid mussel fouling. Pipes, pumps, and raceway structures would be subject to increased operations and maintenance costs. Estimates of about $950,000 per year are based on O'Neill (1997) figures for hatcheries and aquaculture impacts ($5,800 per facility) were applied to 163 facilities in Idaho.

BOATER COSTS

More than 90,000 motorized boats were registered in the state of Idaho in 2007. Potential increases in boater costs are based on estimates for anti-fouling paints and increased per-boat maintenance costs. Estimates of nearly $24 million annually were based on Vilaplana et al. (1994) for increases in boater maintenance costs ($265 per boat).

FISHING USE

Recreational fishing is a $430 million industry in Idaho. Research related to impacts of mussels on fisheries is limited, but reductions of fish numbers are likely. Vilaplana et al. (1994) found a four percent decrease in boater recreation because of mussel introduction. The Idaho estimate of an annual loss of $17.5 million was based on a four percent reduction of use applied to 2,917,972 Idaho fishing trips a year averaging $150 per trip (Grunder et al. 2008).

IRRIGATION

Approximately 56,175 points of diversion (POD) were identified in Idaho by the Idaho Department of Water Resources. Multiple points of use (POU) may be associated with each POD. Each POD and POU could potentially be affected by dreissenid mussels. The mussels can grow up to 0.5 mm per day under ideal conditions and could impact water conveyances that are seasonally dry. Fouling and shell production from mussel establishment is cumulative, and increased fouling and flow reduction could occur in ditches, pipes, pumps, fish screens, and diversion structures over time. Published research on mussel related flow reduction in irrigation systems is minimal, but mussel establishment in pipes and pumps is well documented. The true impacts of dreissenid mussel introduction on irrigated agriculture in Idaho are uncertain, but there is a high likelihood that theses mussels will increase maintenance costs for operations that rely on surface water for irrigation.

Measures Taken

Government, commercial, and public entities have applied a variety of methods to control mussel populations, including aquatic chemical controls, antifouling coatings, physical removal, and mechanical controls. An infestation requires reoccurring, costly mechanical removal of mussels, and the decay of dead mussels can corrode steel and cast iron pipelines, resulting in increased maintenance costs (Western Regional Panel on Aquatic Nuisance Species 2009).

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