Invasive Species Impacts on Transportation INFRASTRUCTURE

U.S. Department of Transportation

Federal Highway Administration

Photographs

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Front Cover

- *First row (1st photo): An abandoned car trapped among a Washington state highway tumbleweed road blockage from New Year's Eve 2019; courtesy Trooper Chris Thorson, Washington State Patrol.*
- *First row (2nd photo): Japanese knotweed growing up through pavement; courtesy Japanese Knotweed Solutions Ltd.*
- *First row (3rd photo): Two large green iguana burrows at edge of pavement along the Florida Turnpike; courtesy Florida's Turnpike Enterprise.*
- *Second row (1st photo): Roadside fire; courtesy California Department of Transportation (Caltrans).*
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- *Second row (4th photo): Speed limit sign covered by kudzu; courtesy Jack Anthony, Landscapes by Jack.*
- *Bottom: Roadway collapse due to soil erosion.*

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16. Abstract

Invasive species present a significant threat not just to ecosystems, but also to our nation's infrastructure, the economy, and cultural resources. Recently the National Invasive Species Council (NISC) has brought attention to the impact invasive species have on federal infrastructure. This is an issue that is not well documented or understood. However, roadside managers have long known that invasive species cause significant and costly impacts to roadway infrastructure, operations, and safety. Roadsides consist of disturbed land that is typically dominated by invasive species when controls are not in place. Because these non-native species have no natural predators or biological control, they proliferate quickly and aggressively costing the State Departments of Transportation millions of dollars each year in maintenance and repairs. These invasive species require extensive management in order to maintain the life of roadway infrastructure and to maintain the safety and operations of roadway. The maintenance task of addressing weeds listed as noxious by State or Federal agencies is daunting and costly in itself, but add to it the species that need to be controlled due to their impacts to roadway facilities and operations, and the cost and task is even more overwhelming. This report highlights some of the significant impacts invasive species have on transportation infrastructure and operations.

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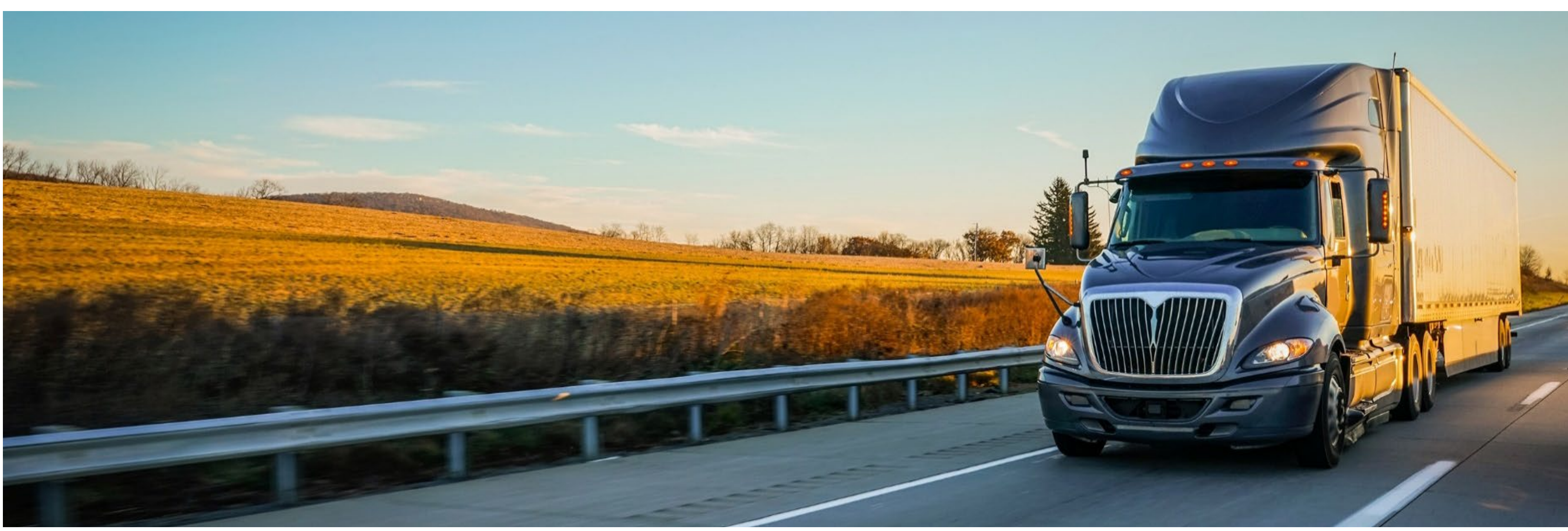
Introduction

This is how much invasive quagga mussels can clog a pipe in 6 months.

Photo taken by Brian Gore.

An invasive species is defined in the United States as a non-native organism whose introduction causes or is likely to cause economic or environmental harm, or harm to human, animal, or plant health. It is estimated that invasive species cost the United States more than $120 billion per year in economic losses. However, much of the research on the economic impacts of invasive species focuses on agricultural impacts with very little attention on infrastructure. In July 2016, the National Invasive Species Council (NISC) released its 2016-2018 *NISC Management Plan* which recognized the need to better understand the impacts invasive species have on infrastructure. For example, zebra and quagga mussels have significantly impacted hydroelectric facilities. The Great Lakes infestation cost the power industry $3.1 billion between 1993 and 1999. The *NISC Management Plan* identifies that non-native species typically enter the United States through ports of entry in urban environments and that some of the first observable impacts by invasive species are on ports and the associated roadway infrastructure that connect products to people.

Although not well studied, roadside managers have long known that invasive species cause significant and costly impacts to roadways, bridges, and culverts. Roadways and waterways are prime corridors for the spread of invasive species. The movement of introduced species is typically seen first along these pathways. The increase in global trade and commerce results in an increase in movement of foreign materials and unintentionally imported species along land and water cooridors.



The *NISC Management Plan* also explains that changes in land use are rendering habitats more susceptible to the establishment of invasive species and amplifies resulting adverse impacts. This is a critical acknowledgment considering that State Departments of Transportation (DOTs) see significant amounts of land use change across the nation. Construction and planning for new roadway corridors, widening of roads, and maintenance and improvements to roadways are occurring continuously throughout the United States. Road construction disturbs natural ecosystems resulting in exposed soils, and changes to soil composition, hydrology, and vegetative community structure. Roadsides consist of disturbed land that is typically dominated by invasive species, when controls are not in place.

Invasive species have a substantial impact on roadway infrastructure, operations, and safety. There are plants that damage pavement, plants that cause erosion along roadway embankments, plants that clog stormwater drainage and retention capacity, plants that block wildlife crossings and roads, plants that are harmful to DOT maintenance staff and travelers, plants that are fire hazards, and plants that block sight lines and roadway signs. In addition, there are animals that burrow in roadway embankments, bridge slopes, and behind retaining walls weakening these structural features. There are also insects, pathogens, and blanketing vines that kill trees in the right-of-way increasing the number of right-of-way hazard trees that need to be removed and increasing fuel for roadside fires.

Because these non-native species have no natural predators or biological control, they proliferate quickly and aggressively costing the state DOTs millions of dollars each year in maintenance and repairs. These invasive species require extensive management in order to maintain the life of roadway infrastructure and to maintain the safety and operations of roadway. The maintenance task of addressing weeds listed as noxious by State or Federal agencies is daunting and costly in itself, but add to it the species that need to be controlled due to their impacts to roadway facilities and operations, and the cost and task is even more overwhelming. This report highlights some of the significant impacts invasive species have on transportation infrastructure and operations.

Japanese knotweed (*Fallopia japonica*) develops large, dense monocultures. A monoculture is an area where only one single plant species is growing. Invasive species quickly establish in areas of land disturbance as seen in this picture.

Photo courtesy Japanese Knotweed Solutions Ltd.

Plants that Damage Pavement and Concrete

Many invasive plants are so aggressive that they will crack through pavement and concrete. One such plant is Japanese knotweed (*Fallopia japonica*). Native to Asia, Japanese knotweed is so destructive it is said that its purpose in its native environment is to break up volcanic rock. It has established in the United States in the northeast, creeping south and west around the Great Lakes and has established in Washington and Oregon. Its formidable roots will grow through pavement and concrete walls causing extensive damage by a plant that is extremely difficult to eradicate.

Japanese knotweed damages and weakens the structural integrity of man-made features such as bridge abutments, roads, sidewalks, parking lots, and foundations. As their roots increase in diameter, they exert pressure weakening and cracking structures. The roots can damage subsurface drainage, underground conduits, septic systems, and other subsurface infrastructure.

Japanese knotweed is extremely invasive and is becoming more widespread. It grows up to eight inches a day, develops dense monocultures, prevents other plants from growing by changing soil chemistry, and can regenerate from both rhizome fragments and stem node fragments.

Japanese knotweed grows up to

8in

Per day

Japanese knotweed is so strong, it can break up volcanic rock.

Japanese knotweed growing up through pavement.

Japanese knotweed roots growing through pavement.

Japanese knotweed growing along a reinforced embankment

Photos courtesy of Japanese Knotweed Solutions Ltd.

Mowing or cutting Japanese knotweed causes the plant to spread as its fragments will re-root. Herbicide has to be timed perfectly because unlike most plants its nutrients flow in only one direction, up for growth in the growing season and down to the roots after it has flowered. Because it is a hollow stem plant herbicide application is often done by injection guns as opposed to broadcast, foliar spray application.

Warning sign to not mow Japanese knotweed. Cuttings of Japanese knotweed will root and grow new plants. Mowing or cutting it spreads the infestation.

Washington State DOT using herbicide injection guns to treat the difficult to eradicate Japanese knotweed.

Photo courtesy Washington State DOT.

Invasive plants will establish and grow in pavement cracks, joints of mechanically stabilized earthen (MSE) walls, and other tiny openings in infrastructure, damaging and weakening these areas causing structural failures and shortening infrastructure life span. Like Japanese knotweed, many plants are even the underlying cause of cracks. Once these plants get a foot hold they make a small problem worse. They increase the rate in which pavement cracks expand, and as they grow, the resulting damage leaves openings for more invasive species to establish, exponentially increasing the damage. They decrease the life of roadway pavement, and they weaken joints of MSE walls associated with overpasses, bridges, and roadway embankments.

Invasive johnsongrass (*Sorghum halepense*) growing in edge of pavement.

Photo courtesy TxDOT.

Kochia (*Kochia scoparia*) growing in pavement.

Photo courtesy TxDOT.

Kochia growing in pavement seam and edge of pavement.

Photo courtesy Washington State DOT.

Another invasive species that will fracture and crack pavement is bermudagrass (*Cynodon dactylon*). Bermudagrass can cause significant damage to roadway if left unchecked. If bermudagrass is growing in roadway right-of-way, it will start to take root along the edge of pavement. Its roots will spread along the surface of the pavement, embedding into the pavement as it spreads with its roots crumbling the pavement along the way.

Project Before Bermudagrass = ***$26k/mile***

Project After Bermudagrass = ***$500k/mile***

Case Study | Bermudagrass

An example of bermudagrass impacts occurred along a rural road in Texas. A stretch of roadway was due for a scheduled pavement sealcoating which is done regularly to provide protection from the elements such as water, oils and U.V. damage. However, prior to sealcoat application, the Texas Department of Transportation (TxDOT) discovered that the road had been taken over by bermudagrass. The damage was so extensive that the road had to be completely rehabilitated, resulting in a substantially more expensive project. A sealcoat project typically averages $26,000 per mile. However, a complete rehab, as required in this situation, averages $500,000 to $600,000 per mile.

Bermudagrass took over nearly a third of this rural road in Texas.

Photo courtesy TxDOT.

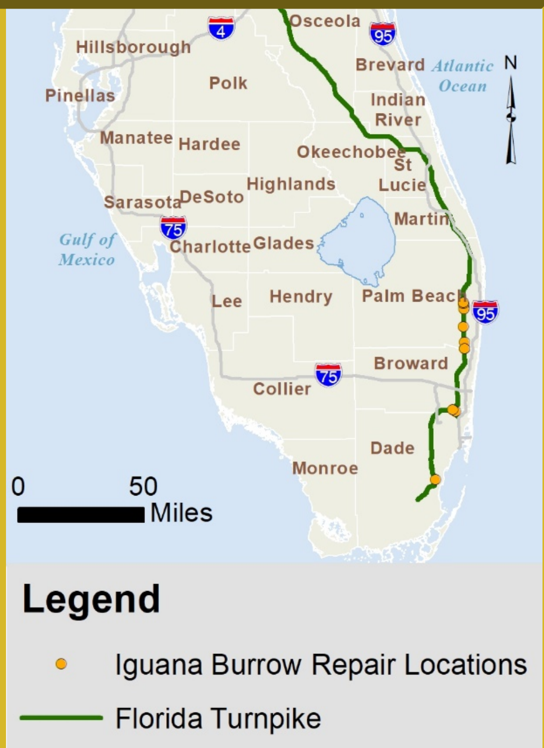
Burrowing Animals Weakening Roadway Embankments and Retaining Walls

Burrowing animals cause significant problems to infrastructure in the United States resulting in erosion problems and weakening structural integrity. Although there are many species of burrowing animals that damage roadway infrastructure, some are more well-known than others. Most notably, is the invasive nutria (*Myocastor coypus*), the large semi-aquatic rodents that caused significant damage to dikes and roadway embankments in Louisiana and the Chesapeake Bay areas. Nutria have been successfully eradicated in these locations, but only after costly damages and through the implementation of large scale eradication programs.

Today, south Florida battles a population explosion of the burrowing invasive green iguana (*Iguana iguana*). While the green iguana has been present in south Florida for decades, their population has exploded in recent years, making newspaper headlines. These large green lizards, native to Central America, can grow up to five feet long and weigh up to 17 pounds. They can dig burrows of up to 80 feet long that consist of interconnected tunnels with multiple entrances, and they seem fond of doing this adjacent to and under infrastructure. Their burrowing activity causes erosion and collapse of sidewalks, foundations, seawalls, berms, and canal banks. They have become an expensive pest along a major roadway in south Florida.

Green iguana along edge of roadway. The population explosion of the invasive green iguana is wreaking havoc in South Florida. They are weakening roadway infrastructure by digging large, extensive burrows along stabilization walls and roadway embankments.

Case Study | Green Iguana



The Florida Turnpike is an expressway system in Florida with a mainline from Miami to central Florida. A portion of this major roadway connector has recently been plagued by the impacts of the invasive burrowing green iguana. They are thriving along the sloped roadway embankments and the canals that run alongside most of the roadway. The iguanas are burrowing at the edge of pavement with potential to cause collapse of the roadway in these areas. The Florida Turnpike even found at least one occurrence of an iguana that dug its way up through the pavement in the center of the roadway. The Florida Turnpike has been diligently identifying burrow locations along the roadway, and between June 2018 and June of 2020 will have spent over $750,000 repairing these areas with geotextiles and riprap armament. In order to further address the problem, they hired a scientist to help with the research and development of either a management or eradication plan of the green iguana along the Turnpike. Obviously, they cannot armor the entire roadway embankment of the 100 miles of the Turnpike currently being impacted, but even the cost of developing and implementing a management plan is costly.

Two large green iguana burrows along the Florida Turnpike in south Florida. These large burrow entrances are right at the edge of pavement. The burrows likely extend beneath the roadway and could cause the roadway to collapse. These areas have to be repaired as quickly as possible.

Photo courtesy Florida's Turnpike Enterprise.

Above is an example of the type of damage that can occur from an iguana burrow beneath pavement.

Invasive Vines Smothering our Right-of-Ways

One of America's most infamous invasive species is the Asian native vine with a name and reputation comparable to Godzilla, KUDZU (*Pueraria montana*). Often called the weed that ate the south, this invasive vine infests highways in the eastern United States and is threatening the midwestern and northwestern states. It is one of many similar invasive vines that can wreak havoc on roadways across the country. While a simple vine, it appears like a giant monster in the right-of-way. Like other invasive vines, it smothers everything living in the right-of-way like a blanket, blocking sunlight and eventually killing all other plants beneath it, including trees. Kudzu is a fast growing vine that can grow one to two feet a day. It can cover roadway signs, creep out into roads obscuring the edge of pavement, and hide dead trees ready to fall in the paths of vehicles or even fall on vehicles themselves. All of these issues have the potential to cause serious injury and even fatalities to travelers.

Kudzu, the so-called "weed that ate the south." Kudzu along Highway 115, Long Branch Road in Lumpkin County, Georgia, has taken over the right-of-way, blanketing everything in its path.

Kudzu covering various road signs.

All photos taken by Jack Anthony, Landscapes by Jack.

Aggressive vines in right-of-ways are a serious safety hazard, but management of aggressive vines is costly. It is reported that power companies spend approximately $1.5 million annually to manage kudzu. Between 2016 and 2018, the Maryland State Highway Administration alone spent $2 million on an 18-month invasive species eradication project with a focus on kudzu and a few other invasive species including another invasive vine called porcelain-berry (*Ampelopsis brevipedunculata*).

Invasive vines blanketing DOT right-of-way also include English ivy (*Hedera helix*) impacting the eastern United States and the west coast, trumpet vine (*Campsis radicans*) in the southeast, and wisteria (*Wisteria sinensis*) in the eastern U.S. Himalayan blackberry (*Rubus armeniacus*) is another invasive vine, often referred to as a shrub because it produces large, dense, thorny thickets. It is a big problem in the rights-of-way in the Pacific Northwest.

Between 2016 and 2018 Maryland State Highway Administration spent

$2 million

on an 18-month eradication project focusing on kudzu and other invasive vines that had taken over highway right-of-way.

Himalayan blackberry growing into the highway in downtown Tacoma, Washington path.

Photo courtesy Washington State DOT.

Monocultures Blocking Sight Lines, Pedestrian Paths, and Roadway

What makes invasive species such a serious problem is that they have no natural enemies or natural control mechanisms like they have in their native range. Therefore, invasive plants have the strong ability to out compete native vegetation in the United States. This commonly results in large, dense areas where a single invasive species has taken over to the exclusion of all other plants, called "monocultures." When the invasive species monoculture in the right-of-way is a large or tall species, or a shrub or tree, this creates a sight line problem where cars cannot see the needed distance in front of them around a bend, an approaching cross road, or a roadway sign. These species also tend to lean out into roads or sidewalks putting cars and pedestrians at risk, causing cars to swerve or pedestrians to move into the roadway. Many invasive species create these problems including the previously mentioned Japanese knotweed, common reed (*Phragmites australis*), and giant reed (*Arundo donax*).

Japanese knotweed encroaching into roadway.

Photo courtesy Pennsylvania DOT.

Berrien County Michigan identified Japanese knotweed taking over its roadsides and especially becoming a problem at intersections. They now control it acknowledging that if it isn't maintained at areas like this "Five Corners" intersection it will block the view of drivers.

Photo courtesy The Herald-Palladium.

Giant reed encroaching into the roadway, obscuring the edge of pavement and blocking the road.

Photo courtesy Caltrans.

Brazilian pepper (*Schinus terebinthifolia*) in Florida is another example of an invasive species that blocks sight lines, road signs, pedestrian paths, and roads. Brazilian pepper is now one of the most aggressive and wide-spread invasive species in the state of Florida. It is a large invasive shrub that has long hanging branches that create a thicket. It establishes dense monocultures by producing a massive amount of tiny red berries that birds eat and disperse. It invades wetland and upland habitats, and it produces a dense canopy that shades out all other plants. According to the University of Florida, there are over 700,000 acres infested with Brazilian pepper in Florida. Florida DOT and local entities are regularly having to remove and trim back Brazilian pepper where it is growing into sidewalks, roads and blocking signs. However, these areas quickly reestablish with new Brazilian pepper sprouts due to the massive amount of berries built up in the soil.

Brazilian pepper along a Florida interstate right-of-way that has to be managed to keep it from encroaching into the roadway and blocking sight lines.

Invasive Species Causing Erosion along Roadsides

Erosion along roadsides can destabilize roadway infrastructure. One of the biggest problems with invasive species is their potential to cause erosion along roadway embankments and all other transportation infrastructure. Roadway embankments are actually a part of the roadway infrastructure. Embankment is the earthen materials used to raise the grade of the roadway. It supports the roadway pavement. Erosion along roadway embankment or around bridges, culverts and other transportation infrastructure can result in major damages.

Erosion can be caused by almost all invasive plants and also by invasive animals in one way or another. Monocultures of invasive plants often create serious erosion problems along roadway embankments, bridge causeways and abutments, and on hillside slopes adjacent to roadway. They impact plant community structure and diversity which is needed to keep soils stabilized. They out compete all other vegetation in many ways such as by sheer density, shading, or by having chemical effects that prevent other species from growing in the area. In addition, many invasive species have shallow root systems or compact root systems that retain soil poorly, further exacerbating the problem. When invasive plants with shallow or compact root systems form monocultures there are no beneficial native plants present to stabilize roadside slopes.

Roadside embankment erosion can cause pavement cracking.

Photo courtesy Ohio DOT or Portsmouth Daily Times.

When soil erosion starts occurring it can get progressively worse and start to erode the soil under the road causing roadway collapse.

Left photo courtesy Caltrans.

The previously mentioned, Brazilian pepper is an example of an invasive species that can cause erosion. As noted, plants cannot grow beneath the dense Brazilian pepper, because sunlight cannot penetrate through its thick canopy. Therefore the area beneath Brazilian pepper canopy consists of unvegetated soil that is susceptible to erosion. Also, Brazilian pepper has to be managed along roadsides to prevent it from blocking sight lines, pedestrian paths, and roads. However, after its removal what is left is exposed unvegetated soil susceptible to erosion along the typically sloped embankments.

Japanese knotweed is another example of an invasive plant species that causes erosion due to its compact root mass, and because its chemical effects to the soil prevents other plants from growing around it. It degrades embankments and impacts resilience to flooding. It has been reported that Japanese knotweed could be the cause of roadway damage from blowouts during recent flooding in the northeast. Kudzu can also cause erosion as it kills all vegetation beneath it by blocking sunlight.

Kudzu has taken over this right-of-way. Removal of this kudzu, or if it dies back, will leave exposed soil and a nightmare of an erosion problem, because it has killed off all other vegetation beneath it. In addition, it is creeping into the road obscuring the edge of pavement, and has begun to cover trees and shrubs potentially killing them and creating hazard trees.

Photo courtesy Georgia DOT.

Tumbleweeds Blocking Roads and Wildlife Crossings

Tumbleweed is not just an eerie prop from old Western movies. It's actually a serious problem in much of the western United States. Tumbleweeds such as Russian thistle (*Salsola tragus*) and kochia (*Kochia scoparia*) blow into roads causing accidents. They regularly block roads, shutting down roads completely until a maintenance crew and heavy equipment can remove them. They also block wildlife crossings, provoking animals to cross roads causing animal collisions. Both Russian thistle and kochia are shrubs that can grow up to six feet in diameter or height and have shallow root systems. Typical gusts of wind uproot or break these shrubs at their stem. They produce thousands of seeds per plant that are dispersed as they tumble.

Tumbleweed road blockage Walla Walla County, Washington.

Photo courtesy Walla Walla County Sheriff's Office.

Tumbleweed blocking a roadway wildlife crossing.

Photo courtesy Washington State DOT.

Russian thistle in the right-of-way can go from looking like this to completely blocking a road in a matter of minutes.

Photo courtesy Washington State DOT.

Case Study | Tumbleweed

Tumbleweed is such a problem that in April 2018 tumbleweed impacted an entire neighborhood in Victorville, California. Nearly 150 homes were covered in tumbleweed with tumbleweed blocking entrance ways to homes and blocking the neighborhood streets. On New Year's Eve 2019 tumbleweed made national headlines when it blocked a Washington state highway with tumbleweed piles as high as 30 feet. Several vehicles were covered by the tumbleweed and people were trapped in their cars. Twelve days later the Walla Walla County Sheriff's Office in Washington reported another road blockage posting an image of a solid wall of tumbleweed across the roadway. Tumbleweed is a serious safety hazard and an expensive maintenance cost to address.

(Top image) An abandoned car found the next day trapped among the Washington state highway tumbleweed road blockage on New Year's Eve 2019.

(Bottom image) A semi-truck covered by tumbleweed on the Washington state highway on New Year's Eve 2019. This semi-truck will carry the plant's seeds to new areas as it travels, an example of how invasive species spread.

Photos courtesy of Trooper Chris Thorson Washington State Patrol.

Fire Hazard Plants and Fire Followers on Roadsides

The summer and fall months of 2019 demonstrated the devastation wrought by wildfires in the western United States. Roadside fires pose a great risk to people, homes, and businesses, but also to transportation infrastructure by damaging guardrails, pavement, signage, culverts, and bridges. Roadside fires also impact roadway embankments due to resulting erosion, and the exposed, unvegetated, loose soils that remain after a fire are susceptible to a more expansive infestation of invasive species.

While any plant can become fuel for fires under certain conditions, not all plant species burn the same. Some species have characteristics that make them serious fire hazards. Fire hazard plants ignite more easily than fire-resistant plants and/or they often burn hotter and/or longer than other plants. There are a number of invasive species that increase the risk and intensity of roadside fires. State DOTs implement fire preventative measures such as mowing “fire guards” alongside roads to help remove fuel sources, but even mowing is limited in the dry season, because mowing blades can create a spark igniting a fire if they hit a reacting surface like a rock.

Wildfire along roadway right-of-way.

Photo courtesy Caltrans.

Culverts and drainage structures can also be damaged by roadside fires and have to be inspected after a fire. The extent of unvegetated loose soil along the roadside embankment shows the potential for serious erosion problems after a roadside fire.

Photo courtesy Caltrans.

Burnt guardrail posts and unvegetated, loose soil susceptible to erosion.

Photo courtesy Caltrans.

One particular species, cheatgrass (*Bromus tectorum*), is of serious concern. Cheatgrass is an aggressive annual grass that is highly flammable. Native to Europe, southwest Asia, and northern Africa, it can now be found throughout most of the United States. However, it is significantly invasive in the western United States where it is highly abundant and commonly found along roadsides. Cheatgrass thrives on disturbance, especially fire. It displaces native vegetation and develops dense monocultures that provide ample, fine-textured fuels that increase fire intensity. Because it re-establishes quickly it also increases fire frequency. Cheatgrass is a "fire follower". It grows faster than many other native grasses after fires allowing it to invade areas quickly and push all other grass species out of the region. It can produce more than 10,000 plants per square yard. In short, more fires means more cheatgrass which will lead to more fires. One example of the impact cheatgrass has on wildfires is the Martin Fire which burned 686 square-miles in Nevada in July 2018. It was one of the nation's largest wildfires as it spread over an enormous swath of Nevada. Expansive fields of cheatgrass in the region are attributed to the devastation of the Martin Fire.

*Cheatgrass is **highly flammable** and is common along roadsides in the western United Sates.*

*The devastation of the **Martin Fire** is attributed to the expansive fields of **cheatgrass** in the region.*

Roadside fire.

Photo courtesy Caltrans.

Another invasive species contributing to roadside fires is scotch broom (*Cytisus scoparius*). Introduced in the mid-1800s, it was originally planted as an ornamental, but now spreads across the western United States posing an enormous fire hazard. Scotch broom is a shrub that can grow up to 10 feet tall. It burns readily and carries fire to the tree canopy. In addition, fire increases the germination of its abundance of seeds making it a "fire follower" taking over roadsides quickly after a fire preventing native, less fire fueling plants from establishing. These two fire hazard invasive species along with many others, including the previously mentioned Russian thistle and kochia, continue to push out native populations, driving a fire fueling loop that state DOTs are having a hard time keeping up with.

Roadside fire.

Photo courtesy Caltrans.

Fire hazard plant scotch broom has taken over the right-of-way along a Washington highway.

Photo courtesy The Horticult.

Scotch broom burns readily and carries fire to the tree canopy.

Invasive Species Increasing Roadside Hazard Trees

Hazard trees pose a serious risk to motorists. Hazard trees are dead or dying trees in right-of-way that have the potential to fall into the roadway. They are a collision hazard and fall directly on cars. A 2009 report on *Human fatalities from wind-related tree failures in the United States* determined that there were 407 deaths from wind-related tree failures in the U.S. between 1995 and 2007. Shockingly, 44% of those were the result of a vehicle struck by a tree or a vehicle that crashed into a downed tree on the road. Hazard trees also contribute fuel to wildfires, which is a significant problem in the western United States.

While trees are always at risk of dying, invasive species accelerate this process and significantly increase the numbers of hazard trees in the right-of-way. Invasive species such as insects, pathogens and vines kill a large number of trees over wide areas quickly. Vines like kudzu and wisteria spread from tree to tree leaving swathes of dead forest. Invasive pathogens and insects likewise affect large areas of forests. State DOTs take hazard tree removal very seriously, but invasive species increasing the rate of tree mortality make the task extremely expensive and difficult to keep up with.

44% of deaths from wind-related tree failures in the U.S. between 1995 and 2007 were the result of a vehicle struck by a tree or a vehicle that crashed into a downed tree on the road.

Photo courtesy Washington State DOT.

Roadside hazard trees that can fall on the road presenting dangerous obstacles for unsuspecting motorists, especially when there is low distance visibility.

Photo courtesy Washington DOT.

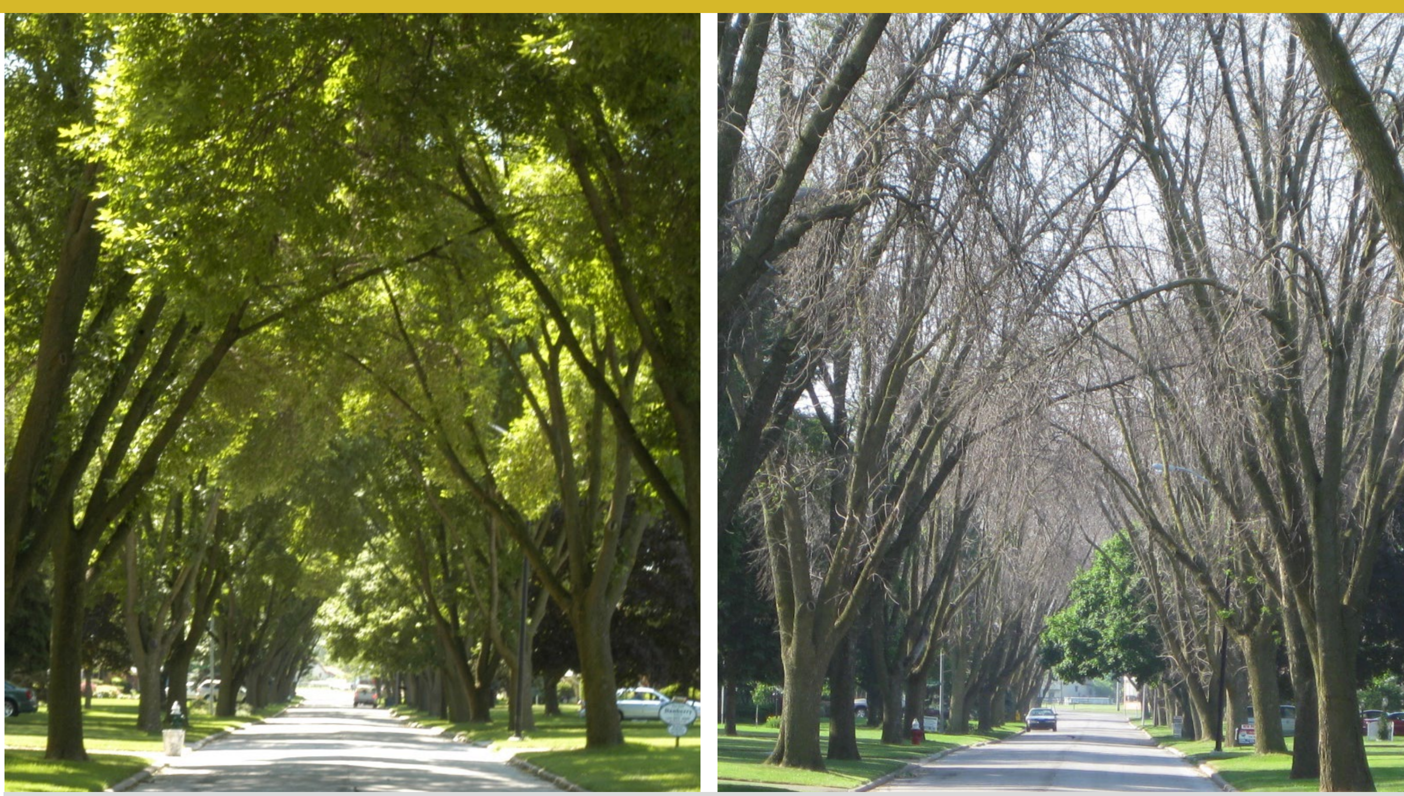
Case Study | Emerald Ash Borer

The emerald ash borer is responsible for the death of tens of millions of ash trees.

Photo courtesy USDA Animal and Plant Health Inspection Service.

Currently, the emerald ash borer (Agrilus planipennis), a beetle native to Asia that feeds primarily on ash trees (Fraxinus spp.), is severely impacting forests throughout the mid-east and eastern United States. According to the U.S. Department of Agriculture, it is responsible for the death of tens of millions of ash trees in 30 states and threatens to kill most of the 8.7 billion ash trees throughout North America. State DOTs are overwhelmed by the number of dead trees in DOT right-of-way.

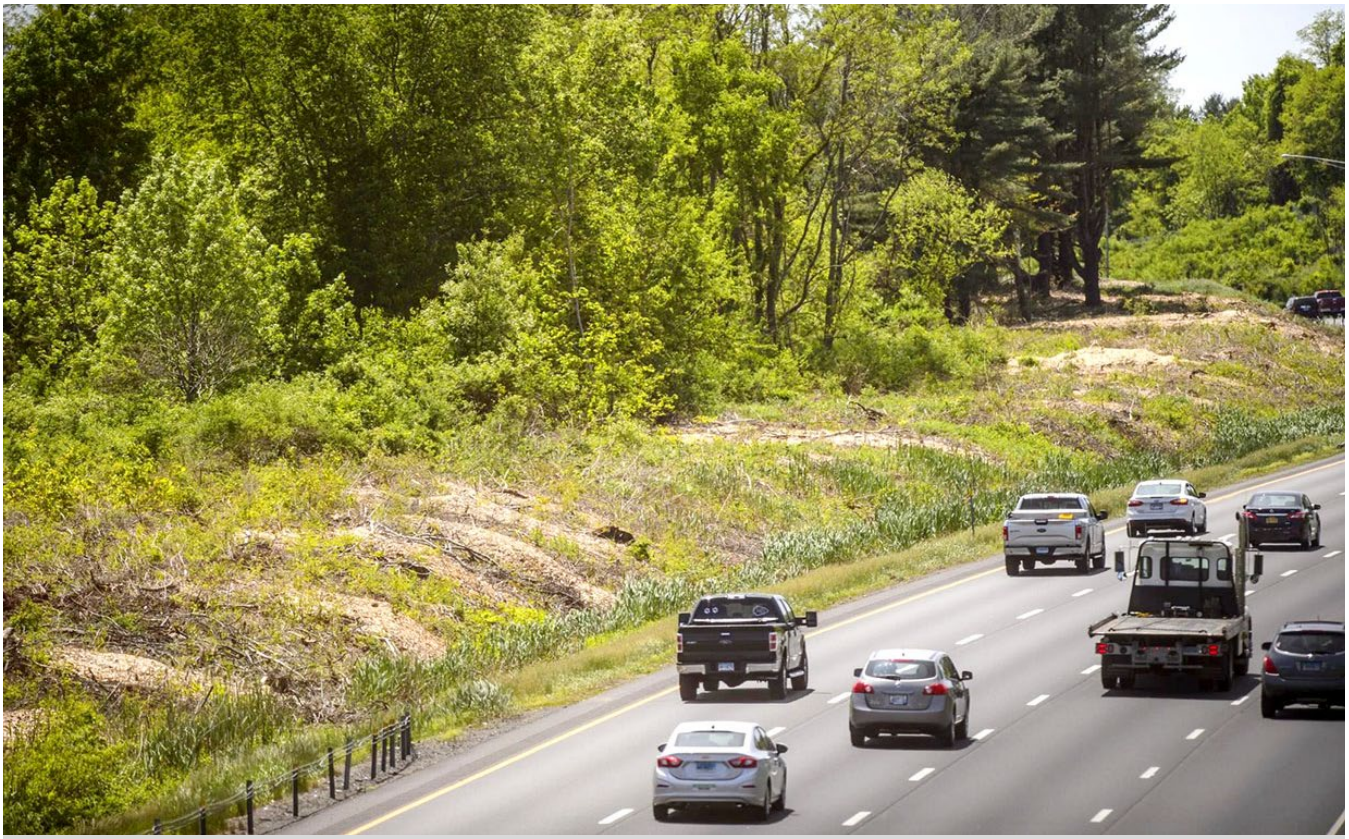
New York State DOT (NYSDOT) counted approximately 300 dead or dying ash trees just along a 1-mile stretch of highway. When considering the cost of removal can be up to $2,000 a tree, the price tag can be as much as $500,000 dollars per mile to remove these hazard trees. Multiply that by 30 states and the many more miles per state and it puts the cost of addressing emerald ash borer impacts within DOT right-of-way well into billions of dollars.



Ash trees along a street in Toledo, Ohio in 2006 and in 2009, before and after being impacted by the emerald ash borer.

Photos taken by Daniel A. Herms.

While the eastern half of the country is being impacted by the emerald ash borer, pine forests in the western states are being impacted by bark beetles. The variety of bark beetles killing trees in the western states are mostly native and not actually exotic invasive species. However, their impact has been no less damaging than the emerald ash borer. Drought in many areas of the west has left trees already stressed and susceptible to disease and parasites. Bark beetles have found favorable conditions allowing their populations to grow rapidly leading to the infestation of millions of acres of trees. It is estimated that there are more than 100 million dead or dying trees in California that have been impacted by drought and bark beetle kill. These dead and dying trees become fuel for wildfires making their removal from the right-of-way even more critical. Following wildfires, the trees become even more likely to fall, becoming more hazardous. In addition, because trees can grow very tall, the threat to the traveling public on roadways can also come from outside the right-of-way. In California, following a roadway fatality caused by a fallen tree that was on land adjacent to the right-of-way, California DOT (Caltrans) has begun looking at neighboring lands to assess the safety threats to people traveling in their roadways.



A Connecticut news article "'We can't cut them fast enough': State to spend millions to cut down 60,000 potentially dangerous trees along Connecticut highways" shows the effort required to address the dead and dying trees resulting from the invasive emerald ash borer and the invasive gypsy moth. The photo above shows the right-of-way following tree removals and piles of wood chips along the roadside.

Photo courtesy Hartford Courant.

Plants that Clog Stormwater Drainage and Stormwater Management Facilities

When plants clog drainage structures such as culverts and ditches, they can cause flooding and ice buildup on roadways, as well as subsequent erosion from flooding. There are many invasive plants across the country that cause these impacts. Examples of such plants include two large invasive reed grasses that are wreaking havoc in waterways in the United States; common reed, also referred to as phragmites (*Phragmites australis*), and giant reed (*Arundo donax*). Some State DOTs report that phragmites is the most aggressive, impactful, and difficult to manage invasive species in their right-of-way. Both species create dense populations along riversides, stream channels, and ditches and both grow over 15 feet tall. They are fast growing and spread quickly by rhizomes, which are creeping rootstalks. They outcompete and displace native vegetation, and their fibrous, dense root mats build up sediment and debris, thus blocking drainage and water flow patterns. They act as dams impeding flow through bridges, culverts and other drainage structures and cause flooding behind it. Not only do they cause significant flooding issues, but they are extremely flammable, which is a major problem in the western United States where the fire regime is more severe and giant reed is prevalent. Their size and density blocks sight lines along roadways, obstructs signs, obscures edge of pavement, and can literally swallow a car. They are attributed to DOT tractor mower rollovers because they obscure visibility and slope grade along the right-of-way.

The density of phragmites prevents water from draining off roads causing flooding in roadway and in the winter creating dangerous ice buildup.

Photo courtesy Indiana DOT.

A vehicle swallowed by giant reed after roadway departure.

Photo courtesy Caltrans.

Case Study | Phragmites

The Green Climber.

Photo courtesy Illinois DOT.

Management of these reed grasses is an unrelenting battle. Illinois DOT (IDOT) reports that controlling phragmites is their biggest challenge. They don't have the manpower, equipment or the funding to adequately tackle the problem. It grows too tall for tractor mowers and too dense for herbicide application, but it's a problem they can't ignore. It clogs roadway drainage systems backing up water onto the roads and increasing ice cover on the roads in the winter. IDOT researched options for dealing with this issue and discovered a remote control tractor slope mower, called a Green Climber. The remote control option eliminates the risk of a tractor driver getting injured in the event of a roll-over and helps with visibility issues. IDOT rented one for a test project to mow phragmites that had caused a drainage blockage associated with an interstate on-ramp. The phragmites had taken over the infield drainage ditch resulting in a major blockage of drainage flow. Restoring drainage required complete removal of the phragmites, including follow-up herbicide treatment, and then re-grading of the ditch.

After the project, IDOT determined that the remote control tractor slope mower was a needed piece of equipment for addressing the state DOT phragmites problem. They purchased one soon after, along with a forestry head attachment that cuts through brush, small trees and shrubs. IDOT has reported that the forestry head attachment has helped to clear areas that are difficult to get through, cutting project time and labor hours significantly. An area that would take an hour to clear only takes minutes with the forestry head attachment. IDOT spent approximately $150,000 on the remote control slope mower and forestry attachment. However, it is the only one for the entire state. They need more, but there is not enough maintenance funding to cover the cost.

Phragmites has taken over this interstate infield which is likely used for stormwater drainage. The sloped embankment and the plant size and density make it difficult and dangerous to mow.

Photo courtesy Indiana DOT.

Hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*) are considered two of the worst invasive aquatic weeds in the United States. Both have a huge impact on roadway stormwater management and require a major effort to maintain. Hydrilla was introduced to the United States by release from fish aquariums in the 1950s and has become a serious threat to bodies of water, reducing water flow in canals and ditches by up to 85%, and clogging and damaging dams and other water control structures.

Water hyacinth, from South America, was introduced in the 1880s as an ornamental pond plant. It also has significant impacts to roadway stormwater management in Florida. It quickly forms dense floating mats that restrict light penetration preventing native plants from growing and it depletes oxygen levels impacting fish. Like hydrilla, it hinders flow in linear drainage ditches and clogs pollution control boxes and water level control structures associated with roadway stormwater management. It also has to be regularly removed to maintain flow and capacity of stormwater management facilities.

Before and after images of mechanical removal of water hyacinth from a stormwater management ditch along the Florida Turnpike.

Photo courtesy Florida's Turnpike Enterprise.

Hydrilla is a submerged plant that can either be rooted or drifting. Amazingly, it can reproduce in four ways making its reproduction rate extremely high. It can reproduce by fragmented pieces, tubers, buds that form at leaf stem bases and break off, and by seed production. It quickly forms thick green mats that fill the depths and widths of stormwater ponds and canals. Not only do these dense mats reduce stormwater management facility capacity, but they prevent sunlight from reaching native plants, fish and other organisms, choking out all aquatic life that provide appropriate water chemistry and treatment of stormwater.

Hydrilla has become a serious problem in Florida. Florida's Turnpike Enterprise has reported that of the 560 stormwater ponds they manage most of them have issues with hydrilla. Hydrilla not only reduces capacity and hinders flow in the linear drainage ditches it also clogs pollution control boxes and water level control structures associated with their stormwater management facilities. They reported that all of the 32 stormwater ponds they manage in Broward County have hydrilla. These ponds total 163,000 acres. Considering that Florida ranks 5th in the U.S. for most annual rainfall, along with a shallow water table combined with a flat landscape, stormwater is taken very seriously. South Florida deals with heavy rainfall events, hurricanes and rainfall averages ranging between 60 and 70 inches a year so maintaining roadway stormwater management facilities and their capacity is an important issue. The management of hydrilla in the stormwater ponds is a huge expense. It requires being mechanically removed, followed by chemical treatment combined with release of grass carp, a fish known to eat hydrilla.

A stormwater pond that captures stormwater from the Florida Turnpike filled with hydrilla.

Photo courtesy Florida's Turnpike Enterprise.

Plants that Are Harmful to People

There are a number of invasive plant species that are actually harmful to people who encounter them. Monocultures of these species in roadside right-of-ways are a significant problem and can harm DOT maintenance personnel and travelers that need to pull over. The two most notable being wild parsnip (*Pastinaca sativa*) and giant hogweed (*Heracleum mantegazzianum*). Wild parsnip spans across the U.S. while giant hogweed can be found in the northeast and the northwest. The sap of both of these invasive plants causes severe chemical burns on contact with the skin, and can cause permanent blindness if it gets in a person's eyes. Monocultures of both of these species are prevalent along roadsides.

Because wild parsnip and giant hogweed are common in many state DOT right-of-ways, they must conduct identification training to help prevent DOT staff from getting injured by these invasive plants. Wild parsnip is particularly hard to identify. It is a significant DOT safety concern especially for maintenance crews conducting weed whacking or mowing. New York State DOT recently assisted with research regarding pollinators within DOT right-of-way, but one research area was so dense with wild parsnip during a follow-up event that the staff could not re-enter the area.

Giant hogweed along roadside.

Giant hogweed.

Photo courtesy New York State DOT.

Wild parsnip.

Photo courtesy New York State DOT.

Photo of giant hogweed burn – 5 days to 5 months after initial exposure.

Photo taken by Bob Kleinberg, courtesy New York State Department of Environmental Conservation.

Summary

Invasive species along roadsides is an infrastructure crisis. Roadsides are where invasive species first establish when introduced to the country and where they flourish. They significantly impact transportation infrastructure, transportation operations, and most importantly are a safety hazard. However, in most states, the funding to address invasive species along roadsides does not compare to the task at hand. The battle state DOTs face addressing invasive species is relentless but necessary. To do it roadside managers need more staff, more equipment, and training.

Integrated management plans and roadside asset management plans have proven to be successful approaches at addressing invasive species in DOT rights-of-way. After initial investment in research and development of these plans, the cost of maintenance of invasive species is typically reduced. However, there will always be new invasive species to address as new non-native species are brought into the country and as current invasive species spread to new parts of the county or become more widespread. Disturbance in DOT rights-of-way will also always pose a problem. Roadside disturbance such as wildfires, cars that run off the road, and animals rooting and burrowing all disturb established vegetation and leave behind exposed soil that invasive species colonize.

State DOTs are faced with the unknowns of potential invasive species impacts resulting from new invasive species or roadside disturbances. Roadside management plans that incorporate early detection and geospatial tracking are essential for understanding and preventing future impacts. This process of early detection allows for the necessary rapid response. It is imperative that the invasive species impacts to transportation infrastructure are brought to light and that roadside managers in state DOTs receive the support needed to develop and implement invasive species management plans that are effective and successful at addressing invasive species in all areas of right-of-way.

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APPENDIX A

Invasive Species that Impact Transportation Infrastructure and their Associated Impacts

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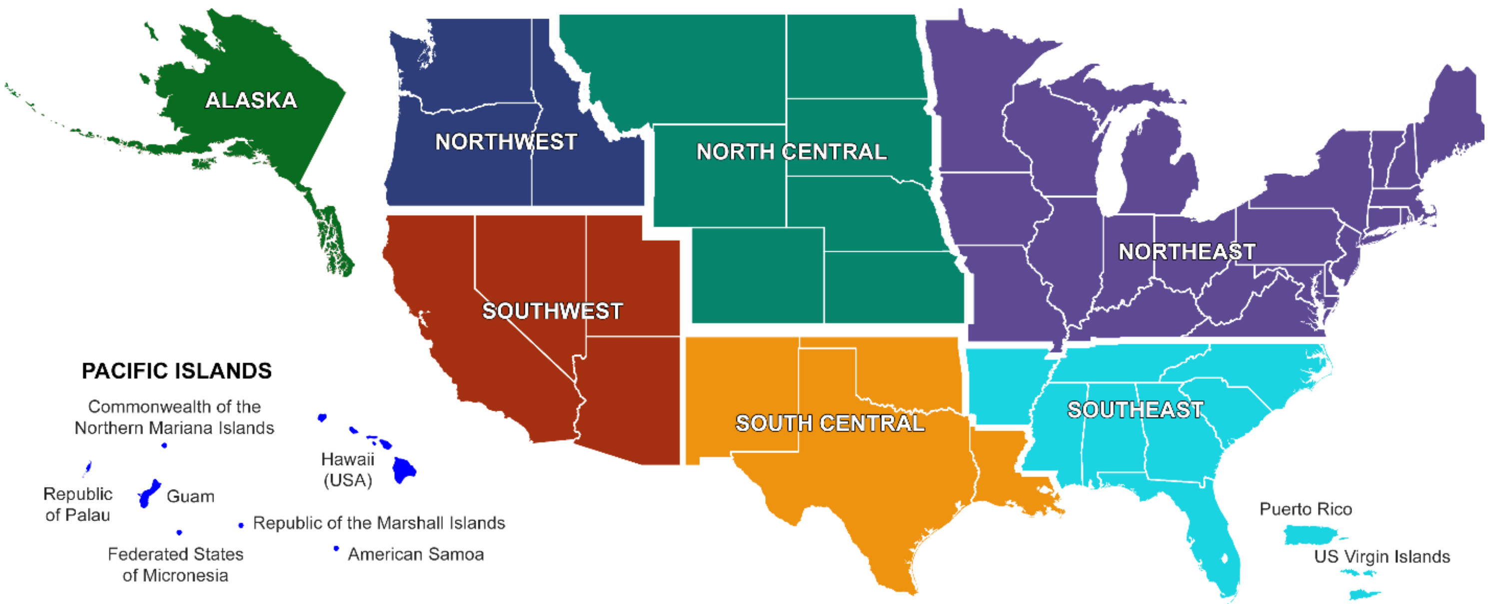
Invasive species have substantial impacts on transportation infrastructure, operations, and safety. Often an invasive species is associated with more than one type of impact. For example, many species that block sight lines are also fire hazards and/or contribute to creating hazard trees and slope destabilization. The following table correlates impacts by species based on the seven impact categories described below.

Impact Category	Description
Damages Pavement/Concrete/ Cement Structures	Invasive species that cause damage to pavement, concrete, and cement infrastructure including plants whose roots crack infrastructure and burrowing animals that weaken the structural integrity of infrastructure causing collapse or failure.
Fire Hazards & Fire Followers	Invasive plants that ignite more easily than fire-resistant plants and/or burn hotter and/or longer can result in roadside fires that impact roadway infrastructure and embankments. Invasive species that create dead or dying trees increase fuel for fires. Fire followers are fire fueling plants that establish quicker than other species after a fire.
Slope & Embankment Destabilization	Invasive species that increase erosion adjacent to transportation infrastructure such as burrowing and rooting animals, invasive plants with shallow or compact root systems, and plants that prevent other soil stabilizing plants from growing either through chemical effects to the soil or by blocking sunlight.
Increases Hazard Trees	Invasive species that increase the rate of tree mortality including insects and pathogens that kill trees and vines that cover and kill trees.
Blocks Sight Lines, Roads, & Sidewalks	Invasive species that obscure visibility of sight line distance, edge of pavement, and roadway signs, and invasive species that block roads, sidewalks, and animal crossings. This includes large or tall species that develop dense monocultures, vines, and tall species such as trees and shrubs that hang out into roadway. This category also includes tumbleweeds.
Clogs Stormwater Drainage/Retention/ Waterways	Invasive species that clog drainage features, structures and stormwater retention facilities causing roadway flooding and/or ice buildup on roads. This includes species that alter water flow patterns that increase erosion adjacent to transportation infrastructure.
Harmful to People	Invasive species that are harmful to DOT maintenance personnel working within the right-of-way and to travelers that need to pull over. This includes species that can burn skin, cause rashes, and/or have harmful thorns.

Regions of Occurrence Acronyms



Region	Acronym
Northwest	NW
North Central	NC
Northeast	NE
Southwest	SW
South Central	SC
Southeast	SE
Alaska	AK
Pacific Islands	PI

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Scientific Name	Common Name	Region(s) of Occurrence	Associated Impacts
Plants			
Ailanthus altissima	Tree of heaven	NW, NC, NE, SW, SC, SE	
Albizia julibrissin	Mimosa tree	NW, NC, NE, SW, SC, SE	
Alternanthera philoxeroides	Alligatorweed	SW, SC, SE	
Ampelopsis brevipedunculata	Porcelain-berry	NE, SE	
Artemisia vulgaris	Mugwort	NW, NC, NE, SW, SC, SE, AK, PI	
Arundo donax	Giant reed	NW, NC, NE, SW, SC, SE	
Bromus tectorum	Cheatgrass	NW, NC, NE, SW, SC, SE, AK, PI	
Casuarina equisetifolia	Australian pine	NE, SW, SC, SE	
Campsis radicans*	Trumpet vine	NW, NC, NE, SW, SC, SE	
Celastrus orbiculatus	Oriental bittersweet	NC, NE, SC, SE	
Cenchrus ciliaris	Buffelgrass	SW, SC, SE, PI	
Centaurea solstitialis	Yellow star thistle	NW, NC, NE, SW, SC, SE	
Cynodon dactylon	Bermudagrass	NW, NC, NE, SW, SC, SE, PI	
Cytisus scoparius	Scotch broom	NW, NC, NE, SW, SE, AK, PI	
Didymosphenia geminata	Didymo	NW, NC, NE, SW	
Dioscorea bulbifera	Air potato	NE, SC, SE, PI	
Dipsacus fullonum	Common teasel	NW, NC, NE, SW, SC, SE	
Egeria densa	Brazilian waterweed	NW, NC, NE, SW, SC, SE, PI	
Eichhornia crassipes	Water hyacinth	NW, NC, NE, SW, SC, SE, PI	
Elaeagnus angustifolia	Russian olive	NW, NC, NE, SW, SC, SE	
Fallopia japonica	Japanese knotweed	NW, NC, NE, SW, SC, SE, AK	

APPENDIX A: Invasive Species that Impact Transportation Infrastructure and their Associated Impacts

Scientific Name	Common Name	Region(s) of Occurrence	Associated Impacts
Plants (continued)			
Hedera helix	English ivy	NW, NE, SW, SC, SE, AK, PI	
Heracleum mantegazzianum	Giant hogweed	NW, NE, SE, AK	
Hydrilla verticillata	Hydrilla	NW, NE, SW, SC, SE	
Imperata cylindrica	Cogongrass	SC, SE	
Ipomoea aquatica	Water spinach	SW, SC, SE, PI	
Kochia scoparia	Kochia	NW, NC, NE	
Leucaena leucocephala	White leadtree	SW, SC, SE, PI	
Ligustrum sinense	Chinese privet	NC, NE, SC, SE, PI	
Lonicera japonica	Japanese honeysuckle	NW, NC, NE, SW, SC, SE, PI	
Lygodium japonicum	Japanese climbing fern	SC, SE	
Lygodium microphyllum	Old world climbing fern	SE	
Lythrum salicaria	Purple loosestrife	NW, NC, NE, SW, SC, SE, AK	
Melaleuca quinquenervia	Melaleuca	SC, SE, PI	
Mimosa pigra	Catclaw mimosa	SE	
Myriophyllum spicatum	Eurasian watermilfoil	NW, NC, NE, SW, SC, SE, AK	
Onopordum acanthium	Scotch thistle	NW, NC, NE, SW, SC, SE	
Pastinaca sativa	Wild parsnip	NW, NC, NE, SW, SC, SE, AK	
Persicaria perfoliata	Mile-a-minute vine	NW, NE, SE	
Phragmites australis	Common reed	NW, NC, NE, SW, SC, SE	
Phyllostachys aurea	Golden bamboo	NE, SW, SC, SE, PI	
Pistia stratiotes	Water lettuce	NC, NE, SC, SE, SW, PI	
Potamogeton crispus	Curly pondweed	NW, NC, NE, SW, SC, SE	

APPENDIX A: Invasive Species that Impact Transportation Infrastructure and their Associated Impacts

Scientific Name	Common Name	Region(s) of Occurrence	Associated Impacts
Plants (continued)			
Prosopis* spp.	Mesquite	SW, SC, PI	
Pueraria montana	Kudzu	NW, NC, NE, SW, SC, SE, PI	
Rosa multiflora	Multiflora rose	NW, NC, NE, SW, SC, SE	
Rubus armeniacus	Himalayan blackberry	NW, NC, NE, SW, SC, SE, AK, PI	
Salsola tragus	Russian thistle	NW, NC, NE, SW, SC, SE, PI	
Salvinia molesta	Giant salvinia	NE, SW, SC, SE, PI	
Schinus terebinthifolius	Brazilian peppertree	SW, SC, SE, PI	
Solanum viarum	Tropical soda apple	NE, SW, SC, SE	
Sorghum halepense	Johnsongrass	NW, NC, NE, SW, SC, SE, PI	
Tamarix ramosissima	Saltcedar	NW, NC, SW, SC, SE	
Toxicodendron radicans*	Poison ivy	NW, NC, NE, SW, SC, SE	
Trapa natans	Water chestnut	NE	
Triadica sebifera	Chinese tallow	NE, SW, SC, SE	
Wisteria sinensis	Wisteria	NE, SC, SE	
Animals			
Boiga irregularis	Brown tree snake	PI	
Iguana iguana	Green iguana	SE	
Myiopsitta monachus	Monk parakeet	NE, SC, SE	
Myocastor coypus	Nutria	NW, NE, SC, SE	
Rattus norvegicus	Norway rat	NW, NE, SW, SC, SE	
Sus scrofa	Wild boar	NW, NC, NE, SW, SC, SE, PI	

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Scientific Name	Common Name	Region(s) of Occurrence	Associated Impacts
Invertebrates			
Adelges tsugae	Hemlock woolly adelgid	NE, SE	
Agrilus planipennis	Emerlad ash borer	NC, NE, SC, SE	
Anoplophora glabripennis	Asian long-horned beetle	NE	
Coptotermes formosanus	Formosan termite	SE, PI	
Cyptococcus fagisuga	Beech scale	NE, SE	
Dendroctonus spp.*	Pine beetles	NW, NC, SW, SC	
Dreissena polymorpha	Zebra mussel	NC, NE	
Dreissena rostriformis bugensis	Quagga mussel	NE	
Ips spp.*	Engraver beetles	NW, NC, SW, SC	
Lissachatina fulica	Giant African snail	PI	
Lycorma delicatula	Spotted lanternfly	NE	
Lymantria dispar	European gypsy moth	NC, NE, SE	
Megabalanus coccopoma	Titan acorn barnacle	SE	
Nylanderia fulva	Rasberry crazy ant	SC, SE	
Perna viridis	Asian green mussel	SE	
Scolytus ventralis*	Fir engraver beetle	NW, NC, SW, SC	
Sirex noctilio	Sirex woodwasp	NE	
Tomicus piniperda	Common pine shoot beetle	NE	

APPENDIX A: Invasive Species that Impact Transportation Infrastructure and their Associated Impacts

Scientific Name	Common Name	Region(s) of Occurrence	Associated Impacts
Pathogens			
Cronartium ribicola	White pine blister rust	NW, NC, NE, SW, SC, SE	
Discula destructiva	Dogwood anthracnose	NE, SE	
Geosmithia morbida	Thousand cankers black walnut disease	NW, NC, NE, SW, SC, SE	
Neonectria spp.	Beech bark disease	NE, SE	
Ophiostoma ulmi	Dutch elm disease	NW, NC, NE, SW, SC, SE	
Phytophthora ramorum	Sudden oak death	NW, SW	 
Raffaelea lauricola	Laurel wilt	SC, SE	
Sirococcus clavigignenti-juglandacearum	Butternut canker	NE, SE	

**Native species*

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