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Midwest Region

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Introduction

The Midwest region includes Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio (Fig. A6.1). Five States border the Great Lakes, in addition to numerous inland lakes and the Missouri and Mississippi River systems. Forty percent of all the water surface area in the continental United States is located within the Midwest. Abundance of water within the region influences trade (shipping ports, river traffic), recreation, agriculture, and ecology. All of these listed factors influence the distribution and impact of invasive species in both terrestrial and aquatic environments.

The diverse and ecologically complex forest ecosystems of the Midwest are dominated by northern and central hardwood forests, bordered by northern boreal forest to the north and prairie ecosystems to the south and west. Forests of the Midwest are productive and valuable, with forest-related businesses ranking in the top 10 for economic importance in every State. The oak-hickory (*Quercus-Carya*) forest type occupies the greatest proportion of the forested area (40%), followed by maple-beech-birch (*Acer-Fagus-Betula*) (15%) and aspen-birch (*Populus-Betula*) (14%). Conifer types, including 9% spruce-fir (*Picea-Abies*) and 6% pine (*Pinus*), are also important, particularly in the Lake States. Bottomland hardwoods rise to importance in this region, with 11% of the area comprising the elm-ash-cottonwood (*Ulmus-Fraxinus-Populus deltoides*) forest type.

The Midwest region also has many large cities and a very high presence of agriculture and industry. Human actions and their interactions with their environment exacerbate the movement and impacts of invasive species. Non-native

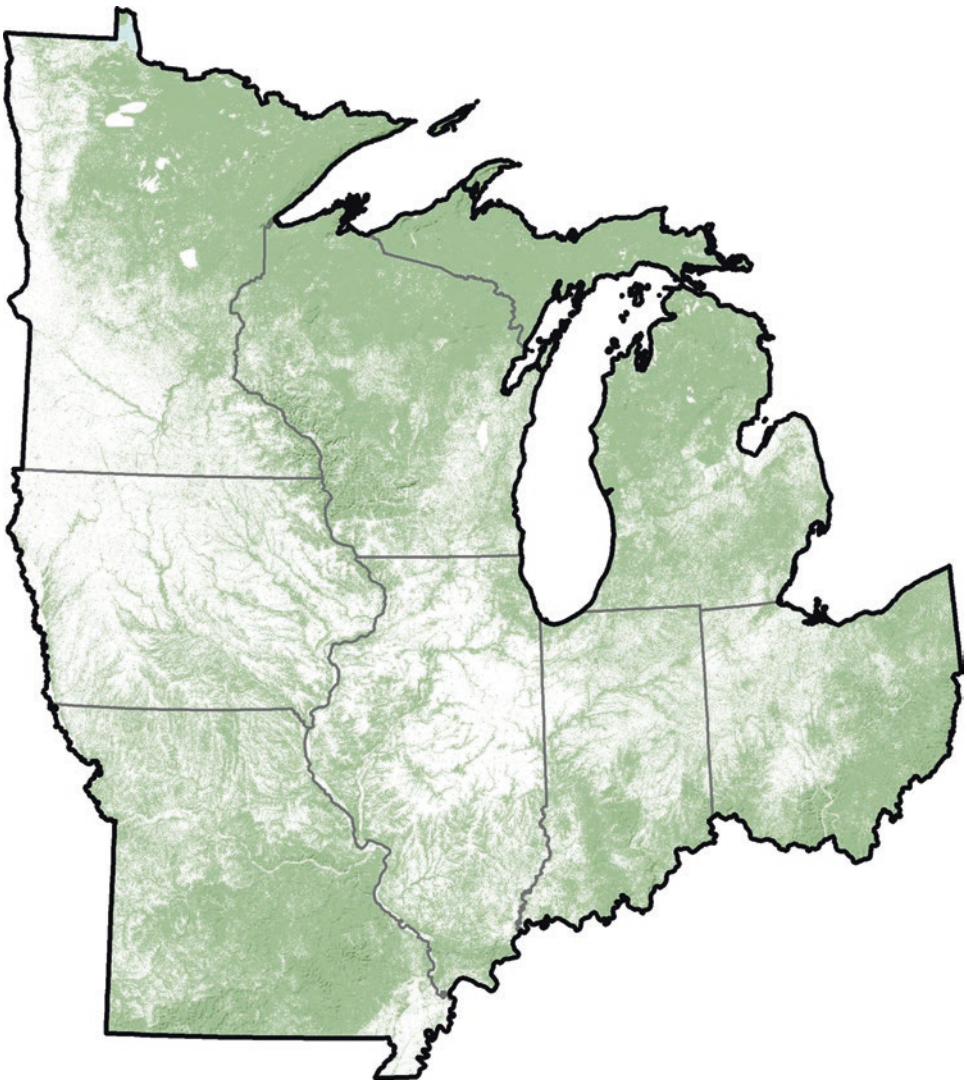

Fig. A6.1 The Midwest region. (Figure courtesy of Daniel Ryerson and Andy Graves, USDA Forest Service Southwestern Region, Forest Health Protection)

invasive species have affected forests and aquatic systems since the time of European settlement, with landscape-level impacts extending into even the most remote areas of the region. We outline selected non-native species below, with focus on current distribution, significant impacts, and current management efforts.

Insect Pests of Trees

Many non-native insect pests occur in the region, and some have caused significant impacts on the region's forests. The focus in this summary is four species that have been of high interest or concern in recent years: gypsy moth (*Lymantria dispar*), hemlock woolly adelgid (HWA) (*Adelges tsugae*), emerald ash borer (EAB) (*Agrilus planipennis*), and Asian longhorned beetle (ALB) (*Anoplophora glabripennis*). Other non-native insects have had impacts that linger in our forests, including larch sawfly (*Pristiphora erichsonii*), larch casebearer (*Coleophora laricella*), Japanese beetle (*Popillia japonica*), birch leafminer (*Profenusa thomsoni*), European pine sawfly (*Neodiprion sertifer*), introduced pine sawfly (*Diprion similis*), and elongate hemlock scale (*Fiorinia externa*).

Gypsy moth caterpillars feed on hundreds of species of trees and shrubs, often causing severe defoliation and contributing to tree decline and mortality. The insect has been the focus of government-sponsored programs for more than 100 years. Currently, gypsy moth is established across Michigan and much of Wisconsin and in portions of Indiana, Illinois, Minnesota, and Ohio. A variety of biological control agents (i.e., parasitoids, predators, and entomopathogens) help regulate gypsy moth populations. In particular, the highly specific insect pathogen *Entomophaga maimaiga* has become widely established in the Midwest and may be contributing to the natural suppression of gypsy moth populations. Management of the insect at the Federal level consists of three distinct strategies (suppression, eradication, and slowing the spread), depending upon where the insect is found (USDA 2012a). Suppression is implemented to reduce adverse effects to trees caused by outbreaks of the insect. Gypsy moth populations in the region remained low between 2007 and 2016, with only Ohio and Wisconsin conducting modest State-led aerial suppression projects on about 44,000 ac (USDA 2017). Eradication is implemented to eliminate colonies of gypsy moth that are detected outside of the currently infested (regulated) area. Between 2007 and 2016, more than 17,000 ac in Indiana, Minnesota, Ohio, and Wisconsin were treated using eradication protocols (USDA 2017). The objective of the Slow the Spread (STS) program, which involves the collaboration of multiple jurisdictions and cooperators, is to slow the natural and short-range human-aided spread of the insect along the leading edge of the area generally infested by the insect. STS is a unique landscape-scale program across a 50-million-ac project area within 11 States from Minnesota to North Carolina. The design and implementation of STS is science-based with the overall strategy founded on research that indicated this was an optimal approach for minimizing spread. Since the start of the program, about 6 million ac have been treated in Iowa, Illinois, Indiana, Minnesota, Ohio, and Wisconsin, mostly employing the application of pheromone flakes to disrupt mating by gypsy moth adults (USDA 2017). Spread rates along the leading edge remained stable in the Midwest region in 2016, while rates across the entire STS project area were low (3.8 km/year).

The hemlock woolly adelgid (HWA) threatens the survival and sustainability of eastern hemlock (*Tsuga canadensis*). Hemlocks are considered a foundation species which define forest structure and control ecosystem dynamics (Havill et al. 2014). The insect, which causes tree decline and mortality, is now present in many eastern States and has recently been confirmed in the Midwest in 13 eastern counties of Ohio and 5 counties in Michigan. The National HWA Initiative, a landscape-scale effort, was established by the USDA Forest Service in 2003 to develop and implement tools to manage HWA and to reduce the adverse effects across the range of eastern hemlock. Current management of HWA in Ohio consists of enhanced survey and monitoring of HWA spread into uninfested areas, as well as the application of systemic insecticides to protect high-value trees in the near term, complemented with the release of biological control agents (predatory beetles) to manage HWA populations in the long term. The HWA predatory beetles *Laricobius nigrinus* and *L. osakensis* have been, and continue to be, released in the infested counties in Ohio. In summer 2015, infestations of HWA were detected in Ottawa and Muskegon Counties in western Michigan. Since then, HWA has also been detected in Allegan, Oceana, and Mason Counties. The State has quarantined the four infested counties and has initiated surveys to delimit the infested area and look for new infestations. Treatments relying heavily on systemic insecticides are being implemented in an attempt to contain local HWA populations. However, it is unlikely that HWA can be eliminated from Lower Michigan. This puts at greater risk more extensive hemlock stands in the Upper Peninsula of Michigan and northern Wisconsin.

Adults of the emerald ash borer (EAB) feed on leaves and larvae tunnel in the phloem. EAB is a significant tree killer that has decimated ash trees across much of the Midwest. Green, white, and black ash (*Fraxinus pennsylvanica*, *F. americana*, and *F. nigra*, respectively) are common and locally abundant. Pumpkin and blue ash (*F. profunda* and *F. quadrangulata*, respectively) are less common but locally important species. All are susceptible to EAB (Klooster et al. 2014). Tree losses from EAB are estimated to be in the hundreds of millions in the Midwest region. A few ash trees have survived in EAB-infested areas which suggests that

there may be some resistance or tolerance in the population (e.g., Anulewicz et al. 2007; Knight et al. 2012; Rebek et al. 2008). First discovered in the Detroit metropolitan area in 2002, subsequent detections have occurred in Ohio (2003), Indiana (2004), Illinois (2006), Wisconsin (2008), Minnesota (2009), Iowa (2010), and Missouri (2008). Today, Federal and State quarantines exist in all or parts of every State in the Midwest region. Ash also is a common street and landscape tree in many Midwestern cities. The eventual cost of treatment, removal, and replacement of infested ash trees in communities is estimated to be as high as $10.7 billion over a 10-year period (Kovacs et al. 2010). Commerce and movement of infested nursery stock and wood products such as firewood are major contributors to the spread of the insect. The current management approach focuses on (1) containment of the insect; (2) regulating the movement of potentially infested materials to areas not infested with EAB; (3) survey and monitoring; (4) public outreach; (5) insecticide treatment to protect high value trees; and (6) management of the insect through the release and establishment of (currently) four biological control agents (parasitoids).

Native to China and Korea, the Asian longhorned beetle (ALB) is a wood borer that can penetrate deep into the wood. It poses a serious threat to the Midwest region's forests. At least 13 tree genera, and more than 100 different tree species, are known to be suitable hosts for ALB (USDA 2012b), although the insect mostly prefers maples (*Acer* spp.), poplars (*Populus* spp.), willows (*Salix* spp.), and elms (*Ulmus* spp.). The Midwest region's forests and urban landscapes include a large number of maples, poplars, and willow. The second confirmed detection of ALB in the United States occurred in the Midwest region, in the Chicago metropolitan area in 1998. An aggressive eradication effort was successful, eliminating the insect from that location by 2008. The next ALB detection in the Midwest region occurred in 2011 in Clermont County, OH, which is more rural compared to the Chicago metropolitan area. Current prevention and eradication protocols include (1) detection and monitoring for ALB via intensive surveys; (2) preventing movement of infested material with established quarantines; (3) public outreach and education; (4) removal and destruction of infested and high-risk host trees; and (5) the use of systemic insecticides. The goal is to eradicate the pest from the woodlots and natural forest stands in this Ohio infestation. ALB may spread faster in natural and managed forests than has been observed in urban and suburban environments (Dodds and Orwig 2011; Dodds et al. 2014). Current survey, monitoring, and control tactics developed for urban areas might need to be modified for rural lands.

Pathogens of Trees

Invasive pathogens have caused serious ecological and economic impacts to Midwestern forests. A few of the more significant current problems are highlighted below, in chronological order of recognition or introduction.

White pine blister rust, caused by the fungus *Cronartium ribicola*, was introduced during reforestation efforts in the early 1900s and is currently distributed throughout the range of eastern white pine (*Pinus strobus*). It causes mortality and top dieback, particularly on environmentally conducive sites. It is considered one of the most limiting factors in growing white pine in the region. The disease is managed by appropriate site selection, pathological pruning, and planting of putative resistant nursery stock (Geils et al. 2010).

Dutch elm disease (DED), caused by *Ophiostoma novo-ulmi* and *O. ulmi*, is a vascular wilt disease that has devastated native elms (*Ulmus americana*, *U. rubra*, and *U. thomasii*) across the region since the introduction of the fungi decades ago (*O. ulmi* in the 1930s and O. *novo-ulmi* in the 1970s). Successive waves of mortality can be attributed to ingrowth of susceptible elms and high populations of insect vectors of the DED fungi in affected areas. The vectors known to exist within the region include the native elm bark beetle (*Hylurgopinus rufipes*) and two non-native species, the smaller European elm bark beetle (*Scolytus multistriatus*) and the banded elm bark beetle (*Scolytus schevyrewi*). Management of the disease in urban settings is accomplished by sanitation to control the bark beetle vectors, chemical injections, and use of DED-tolerant cultivars. Operational trials are underway to evaluate the potential use of putative DED-tolerant elms in the restoration of riparian wild areas (Knight et al. 2017).

Oak wilt, caused by *Bretziella fagacearum* (syn. *Ceratocystis fagacearum*), is a devastating disease of red oak species (*Quercus* subsection Lobatae) that was first described in Wisconsin in 1942. It is considered by many experts to be non-native (Juzwik et al. 2008). The disease rapidly kills infected red oaks. It can also kill white oaks (*Quercus* subsection *Quercus*) in the Midwest, but tree death occurs over several to many years. Disease impact is generally more severe in landscapes with abundant red oaks compared to landscapes where white oaks are common. It is currently found in parts of all States in the region. The oak wilt range is expanding along the northern edge of its distribution. Oak wilt is now at epidemic levels in portions of affected States. Oak wilt is managed in urban and wildland environments by disrupting the overland and the belowground portions of the disease cycle to prevent the establishment of new infection centers and the expansion of existing centers. Current approaches to management on forest lands include preventing movement of diseased material, avoiding wounding during high-risk periods, and disruption of connected root systems (Juzwik et al. 2011).

Butternut canker (caused by *Ophiognomonia clavigignenti-juglandacearum*) was first reported on butternut (*Juglans cinerea*) in Wisconsin in 1967. Its origin

is unknown, but it is believed to have been introduced to North America (Broders et al. 2014). It is now present throughout the natural range of butternut. The disease has killed up to 90% of the butternut trees in the region and may lead to extirpation of the species (Shultz 2003). Silvicultural approaches for butternut regeneration and selection of resistant trees have been proposed in an effort to promote survival of the species (LaBonte et al. 2015). There are no existing tools for management of the disease at this time.

Beech bark disease (BBD), caused by bark canker fungal species that colonize stylet wound damage of an exotic beech scale (*Cryptococcus fagisuga*), was first detected in the region (Michigan) in 2000 (O'Brien et al. 2001). Since that time, beech mortality has become widespread in parts of Michigan. The disease has also been confirmed in eastern Wisconsin and Ohio. As the disease moves through native forests, it kills a significant proportion of American beech *(Fagus grandifolia*), whose nuts are valuable as wildlife food. Mature beech trees can reach large size and are common in parts of Ohio, Michigan, and eastern Wisconsin. BBD is managed on the advancing front through salvage harvesting with retention of smooth-barked and unaffected trees and preventing the movement of infested materials (McCullough et al. 2005). An operational screening effort is underway to identify and propagate beech resistant to beech scale.

Diseases caused by *Phytophthora* species are an emerging concern throughout the region. White oak mortality in Ohio and Missouri has recently been attributed to *P. cinnamomi*, an exotic root-damaging pathogen (Balci et al. 2010). State and Federal plant regulatory agencies continue to monitor nursery stock for the introduction of *Phytophthora ramorum* which could affect the region's oak and ericaceous plants.

Invasive Plants of Terrestrial and Aquatic Systems

There are many non-native invasive terrestrial and aquatic plants distributed throughout the Midwest region. Many of these terrestrial plant species significantly affect the region's forest ecosystems, displacing native plant species and causing substantial damage. Several of the more important woodland species are highlighted below.

Garlic mustard (*Alliaria petiolata*) is a common invader in all Midwestern States (USDA, NRCS 2018). Brought from Europe as a food plant, this shade-tolerant species is now widely found in settings ranging from intact woodlands to disturbed areas (Kurtz and Hansen 2014). Garlic mustard is a biennial and forms large, nearly monospecific patches through heavy seed production, high seed germination rates, allelopathy, and disruption of mutualistic associations (Stinson et al. 2006). Biological control agents, including stem and root boring *Ceutorhynchus* spp. weevils (Becker et al. 2013), have been studied for nearly 20 years and are currently in the final stages of testing. A variety of tactics are employed to manage garlic mustard, including hand-pulling, removal of flowers before seed set, and herbicide application. Seeds are easily moved by animals, people, equipment, and vehicles, and new introductions are difficult to prevent. It can take years to manage large patches of garlic mustard even using multipronged management approaches.

Japanese barberry (*Berberis thunbergii*) was introduced as an ornamental. This species occurs in all Midwestern States but has a wide distribution in Ohio, Michigan, and Wisconsin (USDA NRCS 2018). It occurs in many habitats (closed canopy forests, open woodlands, wetlands, and fields), forming dense thickets and shading out other plants. It is very shade tolerant and grows under a wide variety of growing conditions. Thorns discourage some herbivores, but rabbits can feed on stems through the winter. Japanese barberry spreads through roots and branches that root when in contact with the soil. Birds and other animals eat the bright red berries and can disperse the seeds long distances. This species is typically managed by cutting, pulling, and herbicide use (Michigan DNR 2012).

Common buckthorn (*Rhamnus cathartica*) was also introduced as an ornamental shrub and is now prevalent in Minnesota, Wisconsin, and Michigan, occurring less frequently in the other Midwestern States (USDA, NRCS 2018). It grows as a shrub or small tree in habitats ranging from open fields to forests, forming dense thickets and crowding out native plants. This species has early leaf out and late leaf senescence and can have a longer growing season than other plants, in some cases by nearly as long as 2 months (Harrington et al. 1989). Common buckthorn is spread by birds that ingest fruit which ripens in the late summer. Control of this species can be difficult and can take years, because the thickets are difficult to work in and often resprout after cutting or pulling. Removal is generally followed by herbicide applications to cut stumps (NRCS 2007).

Exotic honeysuckles (*Lonicera* spp.) are common in forest, edges, wetlands, and disturbed areas, occurring in most counties of all Midwestern States (USDA NRCS 2018). Honeysuckles are shrubs, sometimes reaching 10–15 ft. in height, and produce flowers in spring and early summer that are attractive to bees. Fruits ripen in the fall and are dispersed by birds. Like with buckthorn, control is difficult, generally involving repeated efforts of cutting and stump treatments (Ohio State University Extension 2018).

The tree of heaven (*Ailanthus altissima*) is abundant in Ohio, Indiana, and Illinois and has spotty distributions in most other Midwestern States (USDA NRCS 2018). This fast-growing tree can approach 100 ft. in height and is found in many habitats, ranging from closed canopy forests to open fields and urban areas. Due to allelopathy, high seed production, and aggressive suckering, this species can completely dominate areas in which it grows and is difficult

to control with cutting and herbicide stump treatments. Within the last 10–15 years, a soil-borne pathogen (*Verticillium nonalfalfae*) that causes vascular wilt and death in tree of heaven has been found in Ohio, Pennsylvania, and Virginia (Rebbeck et al. 2013). Further research is being conducted on this pathogen and its possible use as a biological control.

Reed canary grass (*Phalaris arundinacea*), phragmites (*Phragmites australis*), and purple loosestrife (*Lythrum salicaria*) are major invasive plants in wetland areas distributed throughout the entire region (USDA NRCS 2018). Biological control with beetles in the genus *Galerucella* has been a success in limiting purple loosestrife (Blossey et al. 2015), while reed canary grass and phragmites are generally managed with consecutive seasonal burns, mechanical removal, and herbicides (Michigan DEQ 2014).

Eurasian watermilfoil *(Myriophyllum spicatum*) is one of several invasive aquatic plants that is distributed widely throughout the region (USDA, NRCS 2018) and which can drastically alter the ecological processes and functioning of aquatic ecosystems. Other invasive aquatic plants in the Midwest include hydrilla (*Hydrilla verticillata*), starry stonewort (*Nitellopsis obtusa*), parrotfeather (*Myriophyllum aquaticum*), and curly-leaf pondweed (*Potamogeton crispus*). Management strategies include harvesting, rotovation, dredging, and aquatic herbicides (Mikulyuk and Nault 2009), but, as with aquatic animals, control of aquatic plants is costly and requires constant effort and investment. Eradication is all but impossible, so preventing new invasions is crucial to avoiding ecological and economic harm.

Invasive Animals of Terrestrial Systems

Invasive vertebrates and noninsect invertebrates threatening terrestrial ecosystems in the Midwest region include feral hogs (*Sus scrofa*) and invasive earthworms. Feral hogs damage native plants and crops and are problematic throughout Missouri, Indiana, Ohio, and Wisconsin. They are managed by trapping and removal, followed by improvement of the degraded habitat. Various species of invasive earthworms have been implicated in the degradation of native plant communities, especially throughout northern Minnesota and Wisconsin (Holdsworth et al. 2007). Best management practices have been developed and implemented to prevent further spread (e.g., Wisconsin Department of Natural Resources 2015).

Invasive Animals and Pathogens of Aquatic Systems

A variety of invasive aquatic animals are recognized as having important negative ecological and economic impacts in the Midwest region. These include fish such as sea lamprey (*Petromyzon marinus*), bighead carp (*Hypophthalmichthys nobilis*), and silver carp (*H. molitrix*); mollusks such as zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. bugensis*); crustaceans such as rusty crayfish (*Orconectes rusticus*) and spiny water flea (*Bythotrephes longimanus*); and pathogens such as viral hemorrhagic septicemia (VHS). These species and many other invasive aquatic animals in the region have disrupted native food webs and altered ecosystem functioning. In many cases, their impacts have reduced the value of ecosystem services and required the implementation of costly management activities to control invasive species and reduce their impacts. For example, sea lamprey, an invasive parasitic fish that feeds on the blood and body fluids of other fish, played a role in precipitous declines of Great Lakes fish stocks in the mid-twentieth century. Scientists discovered an effective lampricide (TFM, 3-trifluoromethyl-4-nitrophenol) in the late 1950s, and its application, along with several other management techniques, has been used to reduce sea lamprey populations. These control efforts are effective, but cost approximately $20 million each year.

In addition to sea lamprey, which invaded the Great Lakes from the North Atlantic Ocean through man-made canals, many other invasive aquatic animals have been introduced to the Great Lakes by the release of ballast water from transoceanic ships. Ship-borne species include zebra and quagga mussels, spiny and fishhook (*Cercopagis pengoi*) water fleas, round gobies (*Neogobius melanostomus*), and Eurasian ruffe (*Gymnocephalus cernua*). These, and some 50 other non-native aquatic species introduced to the Great Lakes by shipping, are estimated to reduce the value of ecosystem services from wildlife watching, commercial fishing, recreational fishing, and raw water usage by more than $100 million annually (Rothlisberger et al. 2012).

Invasive aquatic species that establish populations in the Great Lakes often spread to the rest of the Midwest and beyond. Zebra mussels, which invaded the Great Lakes in the 1980s, are a well-known biofouling organism. They quickly spread to rivers and inland lakes in the States surrounding the Great Lakes and, more recently, have become established in waterways in the Western United States.

Two invasive crayfish species that have serious impacts in the upper Midwest are native to the Southeast: the rusty crayfish and the red swamp crayfish (*Procambarus clarkii*). These species outcompete and hybridize with native crayfish and prey on native fish, crayfish, and gastropods.

Asian carps, including common carp (*Cyprinus carpio*), bighead carp, black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idella*), and silver carp, are invasive fish that present significant concerns for the region. Asian carp species have had major impacts on native fish populations in the Mississippi River basin. Costly electric barriers to reduce the likelihood of Asian carp movement into the Great Lakes have been installed in the Chicago Ship and Sanitary Canal, a man-made hydrologic connection between the Great Lakes and the Mississippi River basin.

Other invasive fish of concern in the region include round goby and Eurasian ruffe, both of which are voracious benthivorous species with high reproductive rates. The piscivorous northern snakehead fish (*Channa argus*) has also been found in isolated locations in the Midwest region and threatens to become more widespread.

Pathogens that are not native to North America also cause harm to native fish species. Several of the diseases associated with these harmful non-native pathogens include viral hemorrhagic septicemia (VHS), salmonid whirling disease, and bacterial kidney disease. Cost-effective control methods are not yet available for most of the aquatic invasive animals in the Midwest region. Research into more effective and less expensive control methods is ongoing. Current management efforts emphasize spread prevention though campaigns to educate the public about the importance of not intentionally or inadvertently moving species among waterways and best practices for avoiding these movements. Direct intervention efforts such as inspecting and pressure washing recreational boats and trailers to remove invasive species propagules and laws requiring that no water be moved among waterways are also important prevention efforts.

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Northeast Region

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Introduction

The Northeast region is heavily forested with a high diversity of hardwood and conifer forest tree species. Northern hardwoods, including sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), yellow (*Betula alleghaniensis*) and paper birch (*B. papyrifera*), and aspen (*Populus tremuloides*) make up 44% of the forests, followed by the oak-hickory (*Quercus-Carya*) type (27%), pine (*Pinus*) types (white-red-jack pine (*P. strobus-P. resinosus-P. banksiana*), loblolly-shortleaf pine (*P. taeda-P. echinata*), and oak-pine) (12%), spruce-fir (*Picea-Abies*) type (11%), and bottomland types (elm/ash/cottonwood (*Ulmus/Fraxinus/Populus deltoides*) and oak/gum/cypress (*Quercus/Liquidambar/Taxodium*)) (5%). Topography, moisture gradient, and disturbance history highly influence where each forest type is found. The Northeast is also water rich, with over 10% of the total area covered by water. Aquatic ecosystems in the region include streams, swamps, lakes and ponds, rivers, and marine and estuarial habitats. In addition, New York has borders on two Great Lakes (Erie and Ontario), while Pennsylvania borders one (Erie).

The Northeast region comprises the New England and Mid-Atlantic States, including Maine, New Hampshire, Vermont, New York, Massachusetts, Connecticut, Delaware, Rhode Island, New Jersey, Maryland, Pennsylvania, and West Virginia (Fig. A7.1), and has a human population density greater than 330 people/mi^2. Many opportunities exist for human-mediated introductions of pests, including international shipping ports, a large urban/rural interface, highly industrialized areas, and high recreational use of forests. This region was colonized by Europeans earlier than most of the rest of the country, and coincidentally has the highest concentrations of invasive forest insects and pathogens in the country (Fig. A7.2). There are many