Microstegium vimineum

INTRODUCTORY

Understory infestation. Photo ©John M. Randall, The Nature Conservancy.

AUTHORSHIP AND CITATION:
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FEIS ABBREVIATION:
MICVIM

NRCS PLANT CODE [225]:
MIVI

COMMON NAMES:
Japanese stiltgrass
Asian stiltgrass
Nepalese browntop

TAXONOMY:
The scientific name for Japanese stiltgrass is *Microstegium vimineum* (Trin.) A. Camus (Poaceae) [15,61,75,102,107,140,156,182,248]

SYNONYMS:
Eulalia viminea (Trin.) Kuntze
Eulalia viminea var. *variabilis* Kuntze [62]
Microstegium vimineum var. *imberbe* (Nees) Honda
Microstegium vimineum var. *vimineum* [102]

LIFE FORM:
Graminoid

DISTRIBUTION AND OCCURRENCE

SPECIES: Microstegium vimineum

GENERAL DISTRIBUTION:
Japanese stiltgrass is native to Japan, Korea, China, Malaysia, India, and the Caucasus Mountains [62,75,140,156,238]. It has invaded portions of Asia where it is nonnative, extending its range into Pakistan, Nepal [76], and Turkey [196]. Japanese stiltgrass is nonnative in the United States and Mexico; Europe; Australia and New Zealand; Africa; South America; and islands of the Atlantic, Pacific, and Indian oceans [238].

In the United States, it is sporadically distributed throughout most of the East and in the Caribbean, from New York south to Texas, Florida, Puerto Rico, and the Virgin Islands [61,75,107]. Japanese stiltgrass was first noted in North America around 1918 in Tennessee [15,54], where it was probably introduced accidentally [54]. It was formerly used as packing material for imported Chinese porcelain, and discarded packaging material containing seeds might have been the source of introduction [232]. Japanese stiltgrass is rare in Florida and other parts of the Southeast [182,248] but is rapidly increasing in Maryland, New York, and other northern states [15,98,187]. It was introduced in New Jersey around 1959 and spread rapidly in that state in the 1990s and 2000s (review by [5]). Roads and waterways appear to be the primary corridors for population expansion [98]; see Site Characteristics and Impacts for information. Plants database provides a map of Japanese stiltgrass distribution in the United States.

HABITAT TYPES AND PLANT COMMUNITIES:
Japanese stiltgrass is mostly associated with forest edges, wetlands, and disturbed areas throughout its US distribution [15]. Shade, low elevation, and moist to mesic soils are important for successful Japanese stiltgrass invasion, with overstory type apparently less important in determining Japanese stiltgrass presence or absence [152] (see Site Characteristics). In its native range, Japanese stiltgrass grows mostly in riparian and mesic areas, being common along shady riverbanks in broadleaved forests [238].

Japanese stiltgrass is often associated with several other nonnative species in the United States. It is frequently associated with garlic mustard (*Alliaria petiolata*) in the East and Southeast ([138]; also see the Vegetation classifications list below). Japanese honeysuckle (*Lonicera japonica*) is often consistently associated with Japanese stiltgrass in the Great Lakes and eastern regions of the United States. In a southern Illinois oak-hickory forest, for example, Japanese stiltgrass cooccurred with Japanese honeysuckle and was also associated with nonnative sericea lespedeza (*Lespedeza cuneata*) and multiflora rose (*Rosa multiflora*) [72]. Japanese barberry (*Berberis thunbergii*) also commonly cooccurs with Japanese stiltgrass across Japanese stiltgrass's distributional range [192]. In New Jersey, Japanese stiltgrass and Japanese barberry cooccurred in bottomland oak-American beech-sweet birch (*Quercus* spp.-*Fagus grandifolia*-*Betula lenta*) forest [56]. Japanese stiltgrass is sometimes associated with Norway maple. In red maple forests of New Jersey, Japanese stiltgrass dominated the ground layer of sites where Norway maple had replaced red maple as the overstory dominant [142].

The following descriptions provide information on where Japanese stiltgrass is known to be present, invasive, or likely to be invasive based upon current knowledge of Japanese stiltgrass's habitat preferences. Japanese stiltgrass is likely invasive or dominant in more plant communities than those described below

Great Lakes and Northeast: Japanese stiltgrass occurs in pine (*Pinus*), oak (*Quercus*)-pine, oak-hickory (*Carya*), and mixed-hardwood woodlands and forests in these regions. In recently burned, mixed-mesophytic woodlands of southern Illinois, overstory codominants of Japanese stiltgrass-infested sites included river birch (*Betula nigra*), black walnut (*Juglans nigra*), sycamore (*Platanus occidentalis*), black cherry (*Prunus serotina*), and winged elm (*Ulmus alata*). Philadelphia fleabane (*Erigeron philadelphicus*), clammy groundcherry (*Physalis heterophylla*), fragrant bedstraw (*Galium triflorum*) and drooping woodreed (*Cinna latifolia*) cooccurred with Japanese stiltgrass in the ground layer [7]. Overstory codominants in a southern Illinois black oak-post oak (*Q. velutina*-*Q. stellata*) forest in early old-field succession included eastern redcedar (*Juniperus virginiana*), flowering dogwood (*Cornus florida*), sassafras (*Sassafras albidum*), and common persimmon (*Diospyros virginiana*). Coralberry (*Symphoricarpos orbiculatus*), poison-ivy (*Toxicodendron radicans*), and nonnative Japanese honeysuckle were commonly associated understory species. Herbs associated with Japanese stiltgrass in the ground layer included big bluestem (*Andropogon gerardii*), golden alexanders (*Zizia aurea*), and blunt-lobe woodsia (*Woodsia obtusa*) [72].

In New Jersey, Japanese stiltgrass occurred in mixed red oak-black oak-chestnut-white oak (*Q. rubra*-*Q. velutina*-*Q. prinus*-*Q. alba*) and white ash-sweet birch-American beech (*Fraxinus americana*-*Betula lenta*-*Fagus grandifolia*) forests. It was less common on sites with high cover of overstory oaks and understory blueberries (*Vaccinium* spp.) than in other hardwood forest types [111]. Overstory associates of Japanese stiltgrass in a sugar maple-red maple (*Acer saccharum*-*A. rubrum*)-sweet birch forest in New Jersey included shagbark hickory (*C. ovata*), bitternut hickory (*C. cordiformis)*, and American elm (*U. americana*). The most common shrubs included black haw (*Viburnum prunifolium*), spicebush (*Lindera benzoin*), and multiflora rose. Although Japanese stiltgrass was the most common groundlayer species, jack-in-the-pulpit (*Arisaema vimineum*) frequently cooccurred in the ground layer [228].

In Maryland, Japanese stiltgrass occurred in the understories of Virginia pine-southern red oak (*Pinus virginiana*-*Q. falcata*) communities. Yellow-poplar (*Liriodendron tulipifera*), red maple, hickory (*Carya* spp.), and black cherry were associated in the overstory [28]. In Maryland and Virginia, Japanese stiltgrass was a component of mixed oak-sweetgum-swamp tupelo (*Quercus* spp.-*Liquidambar styraciflua*-*Nyssa sylvatica* var. *biflora*) communities on the inland coastal plain of Chesapeake Bay [188].

Appalachians: Japanese stiltgrass is common in low-elevation oak-pine forests of the Piedmont [98,189,190]. In Cumberland County, Pennsylvania, Japanese stiltgrass occurred in a red maple/spicebush/skunk cabbage-sphagnum (*Symplocarpus foetidus*-*Sphagum* spp.) swamp [123]. Romagosa and Robinson [190] provide a comprehensive list of shrub, vine, and herbaceous associates of Japanese stiltgrass in an upland loblolly pine (*P. taeda*)-mixed oak forest on piedmont sites in Pennsylvania. The federally endangered glade spurge (*Euphorbia purpurea*) [226] cooccurred with Japanese stiltgrass in the forest's groundlayer vegetation [123].

Japanese stiltgrass reported in mixed-hardwood and riparian communities in Kentucky. In mixed-hardwood forest in the Cumberland Mountains, overstory species associated with Japanese stiltgrass included northern red oak (*Q. rubra*), white oak, yellow-poplar (*Liriodendron tulipifera*), Virginia pine, sugar maple (*Acer saccharum*), basswood (*Tilia heterophylla*), American beech, and yellow buckeye (*Aesculus octandra*). Common shrubs and vines were strawberry-bush (*Euonymus americana*), hillside blueberry (*Vaccinium pallidum*), Virginia creeper (*Parthenocissus quinquefolia*), and common greenbrier (*Smilax rotundifolia*). At 9% to 35% cover, Japanese stiltgrass was the most common graminoid. Associated grasses and forbs included mannagrass (*Glyceria* spp.), slender muhly (*Muhlenbergia tenuiflora*), white snakeroot (*Ageratina altissima*), and panicledleaf ticktrefoil (*Desmodium paniculatum*) [183]. Along the Blue River of Kentucky, Japanese stiltgrass occurred in a big bluestem-indiangrass prairie on gravel wash [88]; the federally endangered [226] Short's goldenrod (*Solidago shortii*) also occurred in the gravel-wash prairie community [88].

Southeast and South: In the Southeast, Japanese stiltgrass often occurs upland from or in dry portions of wet grasslands [205]. On a North Carolina floodplain, Japanese stiltgrass and Japanese honeysuckle comprised nearly 100% of the ground layer and understory of a boxelder-green ash (*Acer negundo*-*Fraxinus pennsylvanica*)-sycamore forest [12].

On the George Washington Memorial Parkway in Virginia, Japanese stiltgrass occurred in the ground layer of old-growth oak-hickory forest. Dominant trees include white oak, scarlet oak (*Q. coccinea*), and chestnut oak, shagbark hickory, and mockernut hickory (*C. tomentosa*). Shrub associates included mountain-laurel (*Kalmia latifolia*), pink azalea (*Rhododendron periclymenoides*), and black huckleberry (*Gaylussacia baccata*). Groundlayer herbaceous associates were winter bent grass (*Agrostis hyemalis*), broomsedge bluestem (*Andropogon virginicus*), common velvet grass (*Holcus lanatus*), and white clover (*Trifolium repens*). Lianas were common in the forest and included trumpet-creeper (*Campsis radicans*), Oriental bittersweet (*Celastrus orbiculatus*), Japanese honeysuckle, and summer grape (*Vitis aestivalis*) [240].

Japanese stiltgrass dominates some deciduous forests of the South. In the Whitehall Experimental Forest, Georgia, Japanese stiltgrass formed a continuous lawn in the ground layer of a red maple-white oak-sycamore forest. The understory was depauperate [20]. In surveys across west-central Georgia, Japanese stiltgrass was detected in 15 of 18 watersheds. Japanese stiltgrass and nonnative species in general were more common in or near urban-rural interfaces, but Japanese stiltgrass was also common in rural locations. Cover of Japanese stiltgrass and Chinese privet (*Ligustrum sinense*) was negatively correlated with overall species richness and overstory reproduction (r= -0.18, P=0.003) for both variables) [124].

Vegetation classifications describing plant communities in which Japanese stiltgrass dominates the groundlayer are listed below alphabetically.

Arkansas

- Japanese stiltgrass is a local dominant in low-lying areas of loblolly pine-sweetgum forests throughout National Forests of Arkansas [148]

Louisiana

- local dominant in low-lying areas of loblolly pine-sweetgum forests on the Kisatchie National Forest [147]

North Carolina

- local dominant in low-lying areas of American beech-white oak forests on the Croatan National Forest [150]
- Guilford Courthouse National Military Park
    - Japanese stiltgrass dominates in depressions within successional loblolly pine-sweetgum/poison-ivy forest communities
    - sweetgum/spicebush/jack-in-the-pulpit/Japanese stiltgrass piedmont small-stream forest communities [242]
- local dominant in low-lying areas of white oak-southern red oak interior forests on the Uwharrie National Forest [149]

Pennsylvania

- Delaware Water Gap National Recreation Area
  - eastern redcedar/autumn-olive (*Elaeagnus umbellata*)/multiflora rose/garlic mustard-annual vernalgrass (*Anthoxanthum odoratum*)-Japanese stiltgrass forest alliance
  - local dominant in planted eastern white pine (*P. strobus*)/Japanese stiltgrass forest types
  - bitternut hickory/sugar maple/Japanese barberry-multiflora rose/white snakeroot (*Ageratina altissima*)-Japanese stiltgrass lowland forest alliance
  - sugar maple-American beech-sweet birch/eastern hemlock (*Tsuga canadensis*)/wild lily-of-the-valley-Pennsylvania sedge (*Maianthemum canadense*-*Carex pensylvanica*)-Japanese stiltgrass forest alliance
  - sugar maple-American basswood/sugar maple/American bladdernut (*Staphylea trifolia*)/Japanese barberry/Japanese stiltgrass forest alliance
  - sugar maple-white ash/sugar maple/Japanese barberry/garlic mustard-white grass (*Leersia virginica*)-Japanese stiltgrass floodplain forest alliance
  - red maple/spicebush/great bladder sedge (*C. intumescens*)-Japanese stiltgrass-jewelweed (*Impatiens capensis*) palustrine forest alliance
  - yellow-poplar-red maple/sugar maple/spicebush/Japanese barberry/Japanese stiltgrass forest alliance
  - sycamore/red maple/spicebush/Virginia wildrye (*Elymus virginicus*)-Japanese stiltgrass-garlic mustard floodplain forest alliance
  - local dominant in black walnut-white ash/multiflora rose bottomland forest alliance
  - local dominant in black cherry-yellow-poplar/autumn-olive/Japanese barberry/Japanese stiltgrass forest alliance
  - local dominant in black cherry-yellow-poplar/autumn-olive/Japanese barberry/Japanese stiltgrass riverine scour alliance
  - silky dogwood (*Cornus amomum*)-multiflora rose/arrowleaf tear-thumb-sedge (*Polygonum sagittatum*-*Carex* spp.)-Japanese stiltgrass wet meadow alliance
  - local dominant in calcareous seep wetland alliances [172,173]
- Eisenhower National Historic Site
  - successional Virginia pine/eastern redcedar/Japanese barberry-multiflora rose/annual vernalgrass-Japanese stiltgrass forest vegetation type
  - sycamore-boxelder-black walnut/silver maple (*Acer saccharinum*)/garlic mustard-spreading sedge (*C. laxiculmis*)-Japanese stiltgrass forest vegetation type [174]
- eastern white pine/Japanese stiltgrass, Norway spruce (*Picea abies*)/Japanese stiltgrass, and ash (*Fraxinus* spp.)/Japanese stiltgrass plantation forests in Evansburg State Park. Nonnative Amur honeysuckle (*Lonicera maackii*) and Japanese honeysuckle often dominate the shrub layer [109]
- Gettysburg National Military Park
  - successional Virginia pine/eastern redcedar/Japanese barberry-multiflora rose/annual vernalgrass-Japanese stiltgrass forest vegetation type
  - sycamore-boxelder-black walnut/silver maple/garlic mustard-spreading sedge-Japanese stiltgrass forest vegetation type [174]
- Hopewell Furnace National Historic Site
  - dry white oak-black oak-yellow-poplar/flowering dogwood/Japanese stiltgrass forest alliance
  - successional black walnut-American elm/spicebush/Japanese stiltgrass forest alliance
  - yellow-poplar/red maple-white ash/spicebush/Japanese stiltgrass forest alliance
  - red maple-green ash/red maple/Japanese stiltgrass palustrine forest alliance [179]
- Valley Forge National Historical Park:
  - dry chestnut oak-black oak/sweetgum/Japanese stiltgrass, silver maple/poison-ivy/Japanese stiltgrass floodplain forest type
  - yellow-poplar-black oak/red maple/ flowering dogwood/Japanese stiltgrass forest type
  - sycamore-boxelder/spicebush/Oriental bittersweet/Japanese stiltgrass riverine floodplain forest type
  - black cherry/yellow-poplar-red maple/box elder/Japanese stiltgrass-garlic mustard forest type [180]

Tennessee

- red maple-white ash/Japanese stiltgrass seasonally flooded forest vegetation type of Great Smoky Mountains National Park [216]
- boxelder/osage-orange (*Maclura pomifera*)/Chinese privet/Japanese stiltgrass riparian forest community type at Stones River National Battlefield [153]

Texas

- often a dominant groundlayer species in low-lying loblolly pine-sweet gum "seminatural" (secondary) forests near Gulf Coast prairies and marshes of eastern Texas [146]

Virginia

- red maple-eastern white pine/Canadian clearweed (*Pilea pumila*)/Japanese stiltgrass plant associations in headwater floodplains and red maple/Virginia creeper (*Parthenocissus quinquefolia*)/Japanese stiltgrass-arrowleaf tear-thumb plant associations in

riparian depressions throughout the state [176]
- Appomattox Court House National Historical Park
  - successional Virginia pine/Japanese honeysuckle/Japanese stiltgrass forest vegetation type
  - successional yellow-poplar/Japanese honeysuckle/Japanese stiltgrass forest vegetation type
  - yellow-poplar-red maple/American hornbeam (*Carpinus caroliniana*)/spicebush/Japanese stiltgrass forest vegetation type [164]
- often a dominant groundlayer species in sycamore-sweetgum-yellow-poplar temporarily flooded forest alliances at Booker T. Washington National Monument [165]
- Colonial National Historical Park
  - tree-of-heaven (*Ailanthus altissima*)-loblolly pine/Japanese stiltgrass forest alliance
  - loblolly pine-white oak-southern red oak/Japanese stiltgrass forest alliance; without Japanese stiltgrass, litter layer of this and other pine communities in the Park is typically sparse
  - disturbed calcareous forest alliances (oaks, pines, yellow-poplar are typical overstory dominants)
  - American beech-white oak-yellow-poplar/Japanese stiltgrass forest alliance
  - black walnut/wingstem (*Verbesina alternifolia*)-Japanese stiltgrass forest alliance
  - yellow-poplar-loblolly pine/Japanese stiltgrass forest alliance
  - sweetgum-yellow-poplar/Japanese stiltgrass forest alliance
  - coastal plain or piedmont small-stream floodplain forest alliances (sweetgum-red maple-yellow-poplar is typical of overstory)
  - red maple-sycamore/Japanese stiltgrass disturbed seep swamp alliances [166]
- Fredericksburg and Spotsylvania National Military Park
  - dominant groundlayer species in successional eastern redcedar woodland alliance
  - dominant groundlayer species in silver maple-boxelder forest alliance
  - dominant groundlayer species in temporarily flooded sweetgum-yellow-poplar forest alliance [213]
- sometimes a dominant groundlayer species in loblolly pine-sweetgum seminatural forest of George Washington Birthplace National Monument [167]
- Petersburg National Battlefield
  - loblolly pine-sweetgum/Japanese stiltgrass seminatural forest type
  - willow oak-pine oak-swamp chestnut oak/common greenbrier (*Smilax rotundifolia*)/Japanese stiltgrass coastal floodplain and piedmont floodplain forest types
  - yellow-poplar-white oak-willow oak (*Q. phellos*)/Japanese honeysuckle/Japanese stiltgrass forest type
  - sweetgum-yellow-poplar/spicebush/Japanese stiltgrass forest type
  - locally dominant in low-lying areas of American beech-white oak/American holly (*Ilex opaca*) forest type [168]
- Richmond National Battlefield Park
  - loblolly pine-sweetgum/Japanese stiltgrass seminatural forest type
  - successional yellow-poplar-oak/Japanese stiltgrass forest type
  - sweetgum-yellow-poplar/spicebush/Japanese stiltgrass floodplain forest type
  - locally dominant in American beech-white oak-northern red oak/American holly forest type
  - successional black walnut-sweetgum/hackberry (*Celtis occidentalis*)/Japanese stiltgrass forest type
  - black walnut/wingstem/Japanese stiltgrass forest type
  - locally dominant in hazel-alder (*Alnus serrulata*) shrubland swamps [169]

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Microstegium vimineum

Cured Japanese stiltgrass in a riparian area. Photo by James H Miller, USDA Forest Service, www.ipmimages.org

GENERAL BOTANICAL CHARACTERISTICS:

Botanical description: This description provides characteristics that may be relevant to fire ecology and is not meant for identification. Keys for identification are available (for example, [15,75,102,140,156,182,248]).

Morphology: Japanese stiltgrass is an annual. It has a straggling to decumbent, loosely branched habit. Aerial culms are 3 to 5 feet (1-1.5 m) long [35,62,75,182]. They may be "wiry" and multibranched [59]. Japanese stiltgrass also produces short to long (depending upon shading), spreading stolons. Japanese stiltgrass populations often form dense lawns of intertwined stolons. The leaves are cauline, with 0.5-inch (1 cm) wide and 3- to 4-inch (8-10 cm) long blades. The inflorescence is a 4.5 to 6 mm, terminal or axillary raceme bearing paired spikelets [35,62,75,182]. Terminal racemes bear chasmogamous flowers, while axillary racemes bear cleistogamous flowers [15]. The fruit is a 2.8- to 3.0-mm, ellipsoid caryopsis. Fruits often have a twisted awn, although some fruits are awnless [35,62,75,182]. In New England collections, presence of awns varied within and among populations [61]. When present, awns are 3 to 8.5 mm long [238]. Root biomass of Japanese stiltgrass is "remarkably small" compared to its aboveground biomass [54,56], and roots are shallow [45,217]. A greenhouse study found that at the end of the growing season, Japanese stiltgrass roots were longest in dry ($\bar{x}$=46 inches (18 cm)) soils compared to roots in soils of moderate (13 cm) and saturated (14 cm) water content. Lateral roots were few, averaging from 3 to 5 per plant [217]. Another greenhouse study found Japanese stiltgrass's roots were shallow and its root biomass was significantly less than its aboveground biomass (P<0.001), so the authors concluded Japanese stiltgrass in unlikely to access moisture in deep soil layers [217].

There has been confusion as to whether Japanese stiltgrass is sometimes perennial [53,54,135], but it is not. Mehrhoff [135] states that this confusion arose from misidentification of white grass—a morphologically similar native perennial—as Japanese stiltgrass. Japanese stiltgrass is distinguished from white grass, with which it often cooccurs, by its ciliate leaf sheath collar and paired spikelets (vs. white grass's glabrous to pubescent leaf sheath and one-flowered spikelets) [135].

Physiology: Japanese stiltgrass is adapted to low-light conditions [39,90,218]. Japanese stiltgrass uses C_4 pathway photosynthesis. It is unusual for a C_4 grass to photosynthesize efficiently under low light conditions, but Japanese stiltgrass is very shade tolerant [12,14,25,90,246] (see Successional Status). In the greenhouse, Winter and others [246] found Japanese stiltgrass grew well under 5% of full sunlight, and the photosynthetic rate of individual leaves was fully saturated at 25% of full sunlight. Dry-matter biomass production was similar under 18% to 100% of full sunlight. Japanese stiltgrass in the understory of a closed-canopy yellow-poplar-white oak forest in Great Smoky Mountains National Park took advantage of occasional, high-intensity sunflecks for optimal photosynthesis [90]. Best Japanese stiltgrass growth occurs on forest-grassland ecotones, where mean photosynthetically active radiation (PAR) is 35% [39]. Ueno [227] provides a description of Japanese stiltgrass's leaf physiology and cellular anatomy.

There are apparently genetic differences in shade tolerance among Japanese stiltgrass populations. Among 3 Japanese stiltgrass populations from Indiana grown in a growth chamber, 2 populations increased specific leaf area in response to shade, while the other did not [51].

Species response to increased levels of atmospheric carbon dioxide can affect plant community composition. High carbon dioxide levels may negatively affect Japanese stiltgrass compared to plant species better able to assimilate extra carbon dioxide. In field experiments in Tennessee, Belote and others [19] found that in a wet year, Japanese stiltgrass produced twice as much biomass under ambient carbon dioxide levels compared to elevated carbon dioxide levels (*P*=0.07). In a dry year, there was no significant difference in Japanese stiltgrass biomass between carbon dioxide treatments. In contrast, Japanese honeysuckle, a common nonnative associate of Japanese stiltgrass, produced 3 times as much biomass under elevated carbon dioxide levels in both wet and dry years [19].

Raunkiaer [185] **life form:**
Therophyte

SEASONAL DEVELOPMENT:
Japanese stiltgrass produces flowers in late summer (August-September); its flowering period is similar across its range (see phenology table below). Plants senesce in early fall [59]. Seed matures until fall frosts and plant death ([72,233], review by [30]), generally from October to December ([116], review by [134]). In the greenhouse, Japanese stiltgrass plants steadily gained biomass from seedling emergence until just before senescence. This ability to continue growth in fall helps Japanese stiltgrass utilize the additional light that becomes available when trees drop their leaves [32].

Japanese stiltgrass phenology		
Area	Event	Season
Carolinas	flowers	September-October [182]
Florida	flowers	fall [248]
Illinois	seedlings establish	May [72]
	flowers	September-October [140]
	disperses seed and dies	October-November [72]
New Jersey	seedlings emerge	late March-late April [30,31]
New York, Central Park	flowers	early September [41]
North Carolina	germinates	March
	stem expands	April
	flowers	September [12]
	disperses seed and dies	October [12,217]
Ohio, southern	germinates	mid-June [33]
Virginia	germinates	March
	flowers	October [46]
Eastern United States	fruits	September-October [15,136,218]
	disperses seed and dies	September-December [136]
greenhouse	seedlings emerge	early May
	plants die	September-early October [32]

REGENERATION PROCESSES:

- **Pollination and breeding system**
- **Seed production**
- **Seed dispersal**
- **Seed banking**
- **Germination**
- **Seedling establishment and plant growth**
- **Vegetative regeneration**

Because it is an annual, Japanese stiltgrass invasion and persistence in a community depend on establishment from the seed bank and/or seed dispersed from off-site parents [72,218]. Within a growing season, however, Japanese stiltgrass spreads vegetatively from stolons [12,35]. Depending upon environmental conditions, Japanese stiltgrass appears adaptable in its relative allocation of carbon to leaves and flowers vs. stolons. In field and greenhouse studies near Memphis, Tennessee, allocation to leaves and flowers was greatest on shaded, fertilized plots, while allocation to stolons was greatest on open, fertilized plots. Still, Japanese stiltgrass showed "extreme plasticity" in morphology, producing both flowers and stolons under a wide range of nutrient and light conditions. A combination of infertile soil and low light was least likely to promote flower and seed production, while fertilization increased stolon production, and low light decreased stolon production. But with a combination of either infertile soil and high light or fertile soil and low light, Japanese stiltgrass compensated for the limited resource and produced both flowers and stolons [35].

Pollination and breeding system: Japanese stiltgrass is both self- and cross-pollinated [91]. Chasmogamy and cleistogamy are noted in nonnative Japanese stiltgrass populations in United States [15] and native populations in Asia [116,211]. Soil moisture and light intensity may affect flower development and breeding. In a population near Charlotte, North Carolina, Barden [12] found about 10% of plants had chasmogamous flowers, with chasmogamous plants mostly growing in moist, open sites. All Japanese stiltgrass plants growing in heavy shade had cleistogamous flowers. In a southern Illinois population with 80% overstory cover, flowers were mostly cleistogamous [72]. In New York, chasmogamous flowers were most common in shady forests interiors. The ratio of cleistogamous:chasmogamous flowers increased in the greenhouse [29].

Genetic studies in the James River Basin of Virginia suggest considerable gene flow among populations, although other studies show interpopulation differences. In the Virginia study, genetic diversity was higher than expected for an introduced species that can self-pollinate, and the author speculated that cross-pollination within and among populations is common in Japanese stiltgrass. There was genetic evidence of long-distance dispersal of Japanese stiltgrass outside the James River Basin [11]. In a greenhouse study, Japanese stiltgrass showed significant differences among families in the number of tillers produced ($P<0.0001$) but not in growth rates [32]. Genetic differences in specific leaf area have been noted among populations [51] (see Physiology).

Seed production is generally high for Japanese stiltgrass [35,233]. Each Japanese stiltgrass tiller typically produces 1 terminal raceme and 2 to 7 axillary racemes [30]. Consequently, a single tiller can bear many flowers, and a single Japanese stiltgrass tiller may produce 100 to 1,000 seeds [59,233]. Seed production varies between years and among populations, however. Based on a study in Great Smoky Mountains National Park, Williams [243] estimated that a single Japanese stiltgrass plant typically produces 77 seeds with 80% to 90% viability. A southern Illinois study found a mean of 81.7 spikelets/Japanese stiltgrass culm. However, spikelet production for 4 Japanese stiltgrass populations varied significantly among populations ($P<0.001$), and seed viability was generally low (33%). The study was conducted during a drought year (1999); even so, seed rain averaged 24.6 seeds/m² (n=34 seed traps) [72]. In New Jersey, Cheplick [29,32] found seed production (both cleistogamous and chasmogamous) averaged about 72 seeds/tiller. The number of tillers produced varied among family lines [32].

Late-season drought can greatly reduce or eliminate Japanese stiltgrass seed production for a cohort [72], and seed production is reduced in low light. In West Virginia, Japanese stiltgrass production of chasmogamous flowers in a dry year was significantly higher in a mesic mixed-hardwood forest than in a dry oak-hickory forest (P=0.03), but there was no significant difference in a year of normal precipitation [95]. In the greenhouse, Japanese stiltgrass produced significantly more fertile spikelets with full sunlight than with 21% or 10% full sunlight ($P<0.05$). There was no significant difference in Japanese stiltgrass fecundity between the 2 lower levels of sunlight [241]. In oak-hickory forests of West Virginia, Japanese stiltgrass seed production was significantly higher along roadsides than in forest interiors [94].

Greenhouse and field experiments showed that Japanese stiltgrass produces some seed in shade. In the greenhouse, Japanese stiltgrass in 2% to 8% of full sunlight produced fewer chasmogamous and cleistogamous flowers and allocated more biomass to leaves compared to plants raised in full sunlight. Field trials produced similar results. In sweetgum-red maple-pin oak (*Quercus palustris*) forests in New Jersey, Japanese stiltgrass plants under the forest canopy produced fewer flowers ($P\leq0.002$) and more leaves ($P<0.003$) than Japanese stiltgrass plants on forest edges. Relative percent of chasmogamous and cleistogamous flowers was similar under the canopy and on forest edges (16% and 11% vs. 6% and 7% of total aboveground biomass, respectively) [30].

Seed dispersal: Reviews indicate that wind, water, animals, and humans disperse Japanese stiltgrass seed [17,191,209,218,238]. Japanese stiltgrass often occurs on floodplains [12,72]. Japanese stiltgrass's close association with sites disturbed by heavy machinery implicates machines, fill dirt, and contaminated hay as potential dispersal agents of Japanese stiltgrass seed [17,209,218]. Rivers, ditches, and roads appear to be primary corridors for population expansion [98]. Japanese stiltgrass fruits are light and float easily and the seeds may survive and germinate after "extended periods" of inundation [233], so flooding is a likely means of seed dispersal (see photo above). Japanese stiltgrass cover was greatest on disturbed (developed or frequently mowed) floodplains near the Mississippi River [12]; however, frequent, severe flood scouring can limit Japanese stiltgrass establishment and spread [72]. Awnless fruits can catch on fur, feathers, and clothing [17,209,218], but because the fruits are small, even awnless fruits can work their way into fur and clothing [218]. A review reports that Japanese stiltgrass seeds often attach to hikers' clothing [134].

Japanese stiltgrass spreads from roads and trails into wildlands [33,128,143,212], but it usually disperses poorly without dispersal agents. Studies in Ohio showed that roadways function as both corridors of dispersal and favorable germination sites for Japanese stiltgrass. On multiple sites in southern Ohio, Japanese stiltgrass was locally abundant in small gravel piles left by road graders and along streams and other water channels [33]. In oak-hickory forests of southern Ohio, Japanese stiltgrass established along roadsides. Dispersal apparently occurred when contaminated gravel was spread; further dispersal occurred from water running through spread gravel. The author speculated that running water disperses Japanese stiltgrass from roadsides into forests. Japanese stiltgrass seeds, which in this experiment had no awns and therefore no apparent adaptations for dispersal, dispersed better than seeds of nonnative multiflora rose (*Rosa multiflora*), which has animal-dispersed seeds, and nonnative coltsfoot (*Tussilago farfara*), which has wind-dispersed seeds [131]. A Japanese stiltgrass population along a hiking trail in southern Illinois was thought to have established from seed dispersed by tractors used to grade the trail and/or by hikers [72]. In mixed-hardwood communities in the Blue Ridge Mountains of North Carolina, Japanese stiltgrass presence was positively correlated with proximity to streams, closed-canopy sites, and developed sites ($P<0.05$) [115]. Studies in Ohio showed that roadways function as both corridors of dispersal and favorable germination sites for Japanese stiltgrass [33]. In the Green Ridge State Forest, Maryland, Japanese stiltgrass presence was positively associated ($P<0.001$) with sites 30 to 490 feet (10-150 m) from roads [143].

In closed-canopy forests on the Monongahela National Forest, West Virginia, soil-stored Japanese stiltgrass seed was found only within 30 feet (10 m) of roadsides, although patches of Japanese stiltgrass were found in forest interiors. The author surmised that secondary seed dispersal accounted for Japanese stiltgrass establishment in interior locations. Average seed spread rate across locations was 0.95 foot (0.29 m)/year [96]; possible methods of dispersal were not investigated.

Seed banking: Japanese stiltgrass seeds apparently have short-term persistence in soil [12,72,199,230]. Longevity of soil-stored seed is usually estimated at 3 to 5 years [12,72,218], although one author suggests that seeds may live less than 1 year [243]. On a North Carolina site, soil-stored Japanese stiltgrass seed remained viable for at least 3 years. On a sloped seep in Pennsylvania, most viable Japanese stiltgrass seeds were collected at 0- to 4-inch (10 cm) depths. Most often, Japanese stiltgrass seed was found in the soil when Japanese stiltgrass plants were present in aboveground vegetation [191]. In the greenhouse, a mean of 87.5 Japanese stiltgrass seedlings emerged from 400-cm² soil samples, which were collected in a red maple forest in Arkansas [241].

Japanese stiltgrass seed occurs in waterlogged soils and along waterways as well as in soils beneath upland plant communities. Japanese stiltgrass seed was collected from the seed bank of a tidal freshwater marsh along the Delaware River in New Jersey [120,121]. In swamplands of the Delaware River, Japanese stiltgrass appeared to be replacing native sedges (Cyperaceae) in the ground layer [121]. By the Potomac River in Virginia, Japanese stiltgrass seeds were collected during spring from the seed bank of the high-drift shoreline. Japanese stiltgrass seeds were not found on the driftline in other seasons, and Japanese stiltgrass seeds were not found in any season by trawling along the water surface. The plant community above driftline was a narrowleaf cattail-arrow arum (*Typha angustifolia-Peltandra virginica*) tidal freshwater marsh [89].

Occasional seed crop failure is probably not limiting for this species. Given a persistent seed bank, Japanese stiltgrass may establish in high densities the year following poor seed production [72].

Germination: Although seed production can be high [35,233], few seed germination studies have been conducted as of this writing (2010), so Japanese stiltgrass germination requirements are unclear. On some sites, Japanese stiltgrass appears to require cold stratification (review by [97]), which is accomplished in the field by overwintering. A greenhouse study using seed from North Carolina found that fresh seed was not immediately germinable, while seeds stratified for 90 days showed 100% germination [104]. However, Williams [243] reported immediate germination of Japanese stiltgrass seed collected in Great Smoky Mountains National Park.

Open sites and little or no litter favor Japanese stiltgrass germination. In oak-hickory forests of southern Ohio, Japanese stiltgrass germination in general was higher on open than on closed-canopy sites. Roadsides were particularly favorable for germination; Japanese stiltgrass seed sown along roadsides showed significantly better germination than seed sown in closed-canopy forest ($P<0.05$) [33,131]. Matlack [131] found that Japanese stiltgrass "completely saturates the roadsides in which it occurs". In a white oak-yellow-poplar forest in Tennessee, litter removal down to mineral soil or litter removal to mineral soil plus mineral soil disturbance significantly increased Japanese stiltgrass spread compared to plots with undisturbed litter ($P=0.05$) [130]. On the Wayne National Forest, Ohio, seedlings rarely occurred on plots with deep litter; they were concentrated on microsites with exposed mineral soil ($P<0.003$) [33]. In another experiment on the Wayne National Forest, forest floor disturbances that reduced litter were the most important factor in successful Japanese stiltgrass germination (abstract by [212]).

Seedling establishment and plant growth: Japanese stiltgrass may initially establish in large numbers, experience high seedling mortality, then form thick lawns via vegetative expansion of remaining plants. In southern Illinois, Japanese stiltgrass established at a mean density of 43 seedlings/m². Plant mortality was greatest (≥50%) in early seedling establishment (mid-March), dropping to about 20% by July [72]. In central New Jersey, Japanese stiltgrass seedling density in March and April averaged 1,963 seedlings (SD 652)/m², and the seedlings averaged 2 to 6 inches (5-15 cm) in height [30]. Barden [12] estimated the number of plants produced from 1983 to 1986 on a 2-m² plot in North Carolina averaged 1,000 (in 1983), 256 (1984), 44 (1985), and 0 (1986), respectively. Density of Japanese stiltgrass on another 2-m² study plot on the North Carolina site averaged 857 (in 1984), 47 (1985), and 29 (1986) [12].

Sunlight and moist soil increase the chances of Japanese stiltgrass establishment and favor its growth (review by [236]). Establishment and spread are limited in shaded environments [95]. On shaded sites, more carbon is allocated to leaves and aerial stems than to stolons [35] and flowers [95]. However, Japanese stiltgrass is well adapted to shady conditions. It can establish, grow, and produce some seed in as little as 5% of full sunlight [233].

In oak-hickory forests of West Virginia, Japanese stiltgrass was significantly taller along roadsides than within forest interiors; Japanese stiltgrass cover and spread were also higher along roadsides than in forest interiors[94]. On rural and wildland sites in New Jersey, seedling emergence, growth, and seed production of sown Japanese stiltgrass seed was significantly greater on an open lawn than in an interior red maple-shagbark hickory-sweetgum woodland (P<0.05). Japanese stiltgrass density on the lawn averaged 1,573 plants/m², while density in the interior woodland averaged 709 plants/m². Seed production was positively correlated with light (r^2=0.06, P>0.05) but not with Japanese stiltgrass plant density or soil moisture [31].

Litter apparently impairs Japanese seedling establishment [54,152,160], although it may not affect later growth [193]. In a landscape-level study of 3 white oak-sweet birch forests in New Jersey, sites with Japanese stiltgrass had less litter than adjacent uninvaded sites [54]. In an oak-yellow-poplar plantation in southwestern Tennessee, plots where litter was removed in winter experienced 4.5 times the invasion of Japanese stiltgrass compared to plots where winter litter was left intact (P<0.001). At the end of the growing season, Japanese stiltgrass on plots without litter had spread an average 5.45 feet (1.66 m), while Japanese stiltgrass spread on plots with litter averaged 1.20 feet (0.37 m). Japanese stiltgrass cover averaged 48% and 5% on plots without and with litter, respectively. The authors suggested that increased light as a result of litter removal favored Japanese stiltgrass germination and growth [160]. In a harvested white oak-yellow-poplar forest in Tennessee, Japanese stiltgrass spread was greater with litter removal or soil disturbance than on undisturbed sites [129,130]. Measured from plot edges, the distance at which 90% of Japanese stiltgrass plants occurred (P=0.02) and overall mean distance of Japanese stiltgrass spread (P=0.04) were significantly farther with litter removal than without. Outlier Japanese stiltgrass plants (those farthest from the population center) may be of greatest concern in terms of Japanese stiltgrass spread. The distance of outlier Japanese stiltgrass plants was significantly farther in litter-removal and soil-disturbance plots than control plots (P=0.02) The authors suggest that disturbing litter may increase Japanese stiltgrass invasion and spread in eastern hardwood forests, while leaving litter layers intact may slow Japanese stiltgrass invasion [129].

While litter may inhibit Japanese stiltgrass establishment, a greenhouse study suggests litter may not impede growth after seedlings establish. Using soils from oak-hickory and red maple forests of New Jersey, Ross [193] found that regardless of soil origin, leaf litter additions did not significantly decrease growth of established Japanese stiltgrass plants compared to soils without added litter. Additional greenhouse studies using soil from the 2 forests showed arbuscular mycorrhizae had no effect on Japanese stiltgrass growth. Japanese stiltgrass roots were susceptible to arbuscular mycorrhizal colonization, but Japanese stiltgrass height growth was similar with and without arbuscular mycorrhizal colonization [193].

Based on shade and litter manipulations in white oak-red oak-shagbark hickory, red maple-American elm, and white ash-yellow-poplar forests in New Jersey, Schramm and Ehrenfeld [197,198] suggested that deep litter, shade, or their interactions may limit Japanese stiltgrass spread (P=0.05 for all variables). Only seedlings with no litter or a litter layer one-half of average (~0.8 inch (2.2 cm)) showed "substantial" survivorship. There was a trend towards decreasing Japanese stiltgrass cover with increasing successional stage. Japanese stiltgrass was "effectively excluded" where American beech, a late-successional species that casts deep shade at maturity, dominated the canopy, while open, successional red maple- and white ash-dominated forests had 22% to 30% Japanese stiltgrass cover. Oak-hickory forest supported intermediate levels of Japanese stiltgrass (5-8% cover). Regardless of successional stage, there was a trend toward decreasing Japanese stiltgrass invasion with increasing stand size (r^2=0.33) [198]. The authors suggested that generally, loss of the shrub layer due to heavy white-tailed deer browsing could accelerate Japanese stiltgrass spread [197,198]. Interactive effects of white-tailed deer and Japanese stiltgrass on stand structure and plant species composition are discussed further in Impacts; see Successional Status for further information on Japanese stiltgrass and shade.

Rauschert and others [186] present a model of Japanese stiltgrass population growth based on broadcast seeding experiments in an oak-hickory-eastern white pine forest in Pennsylvania.

Several other site characteristics and stand structure apparently affect Japanese stiltgrass regeneration. In North Carolina, Japanese stiltgrass regeneration was negatively correlated with high soil pH (5.5 vs. a median of 5.1); high levels of soil potassium, zinc, and calcium; high percent silt (18% vs. 10%); deep litter (8.6 vs. 5.5 cm); high cumulative PAR on an overcast day (0.72 vs. 0.57 mol/m²/day); and high leaf area index (LAI) of other species (1.3 vs. 0.7)[12]. In southern Illinois, reproductive success was correlated with soil conditions and canopy cover. Reproduction increased with increasing availability of soil cations and sand content and decreased with increased soil silt content and canopy cover (P<0.05 for all variables) [72].

Vegetative regeneration: Within a growing season, Japanese stiltgrass increases vegetatively by tillering [31,98] and by stolons [98], sometimes forming dense, monospecific stands through vegetative spread [15]. Because Japanese stiltgrass is an annual, the vegetative shoots do not survive through the next growing season [72]. High vegetative biomass does, however, increase the likelihood of reproductive success by increasing photosynthate gain and thus the potential for high seed production. High light and other favorable conditions maximize vegetative growth [29].

SITE CHARACTERISTICS:
Japanese stiltgrass is common in disturbed areas [15,62,140] including roadsides, shorelines [62,140], floodplains [12], and "waste places" [62,140]. It is most common on disturbed soils at low to middle elevations and prefers moist, continental climates.

Japanese stiltgrass is strongly associated with disturbed forest sites, especially roads. The Virginia Department of Conservation and Recreation [233] stated that Japanese stiltgrass is common on disturbed soils and can rapidly spread onto undisturbed soils once established nearby. In white oak-eastern hemlock forests of Pennsylvania, Japanese stiltgrass was about 7 times more likely to occur on disturbed than on undisturbed sites [175]. In the Green Ridge State Forest, Maryland, Japanese stiltgrass presence was positively associated with disturbed soils (P<0.001) [143]. In sweetgum-sycamore and loblolly pine-white oak-sweetgum forests of Mississippi, Japanese stiltgrass was positively associated with canopy gaps and flooding (P<0.001 for both variables) [21]. On 2,000 sites within oak-hickory forests of western Virginia, Japanese stiltgrass cover was positively related to road length (P=0.04) and length of the road relative to total area of the watershed in which it occurred (P<0.001). Japanese stiltgrass was rare in forest interiors relative to its abundance on roadsides, and Japanese stiltgrass by roads gained more biomass than Japanese stiltgrass growing in forest interiors (P<0.001) [128].

In a seeding experiment in an oak-hickory-eastern white pine community in Pennsylvania, Nord and others [152] concluded that disturbance and soil properties were more important to successful Japanese stiltgrass invasion of a site than the plant community type. They found that litter disturbance increased Japanese stiltgrass population expansion for the first 2 years of Japanese stiltgrass invasion compared to sites with undisturbed litter (P<0.02) and that populations consistently declined on closed-canopy sites. Disturbance × environment interactions were not significant for Japanese stiltgrass population growth [152]. See Nutrients for more information on this study.

Soils: Japanese stiltgrass prefers damp or wet soils ([12], review by [233]), although it does not tolerate standing water for "extended periods" of time (review by [233]). It also establishes on dry upland soils [209]. On the Jefferson National Forest and in Mountain Lake Wilderness, Virginia, Japanese stiltgrass occupied either damp sites without standing water or sites with "highly disturbed" soils such as gravel and dirt mounds by roadsides [144]. In southern Ohio, Japanese stiltgrass was "particularly dense and vigorous" in swales and moist soil [33]. In a yellow-poplar-common persimmon-sweetgum forest in North Carolina, Japanese stiltgrass successfully "outcompeted" native understory species on floodplains and midslopes but not on upland sites [230]. In Florida, Japanese stiltgrass is common on wet hammocks [248]. In the greenhouse, Japanese stiltgrass's relative growth rate was fastest in soil with 30% water content (P<0.05), but it persisted and produced some seed in flooded soils and in soils with <10% water content. The authors attributed Japanese stiltgrass ability to invade a site, in part, on its ability to tolerate "contrasting and extreme soil water conditions" [217].

Japanese stiltgrass is common on silty to sandy loams [12,59,72,183] and on clays [59,98]. In deciduous wetlands of New Jersey, Japanese stiltgrass was positively correlated with percent clay in soil (P<0.05) [55]. Japanese stiltgrass an indicator of red clay soils in the Piedmont region [98].

Soil pH is usually mildly acidic to basic on sites with Japanese stiltgrass [59,72,218]. A survey in Maryland and Washington, DC, found that sites with Japanese stiltgrass ranged from pH 4.8 to 5.8 [187]. On mine spoils in Kentucky, Japanese stiltgrass grew on loamy soils with pH ranging from 4.6 to 6.3. It was absent from an extremely acidic site (pH 4.4) [183]. In an Illinois study, soils supporting Japanese stiltgrass were generally acidic and nutrient poor [72].

Some studies have found that Japanese stiltgrass was positively associated with basic soils [37,152] or that it raises soil pH [56]. In deciduous wetlands of New Jersey, Japanese stiltgrass was positively correlated with nonacidic soils (P<0.05) [55]. In white oak-eastern hemlock forests of Pennsylvania, sites most likely to support Japanese stiltgrass had basic soils and low understory cover [175]. Studies in Tennessee oak-pine [37] and New Jersey oak-hickory [111] forests showed high soil pH favors Japanese stiltgrass, while a study in a oak-hickory forest of southeastern Ohio showed no significant increases in Japanese stiltgrass abundance with lime additions to soil [73]. In mixed-hardwood forests of New Jersey, there was no significant relationship between Japanese stiltgrass invasion and soil pH [198].

Nutrients: Based on limited studies, Japanese stiltgrass may prefer soils with generally high mineral content but low levels of ammonium. In an oak-hickory-eastern white pine community in Pennsylvania, phosphorus level (P=0.01), potassium level (P=0.01) moist soil (P<0.001), and high pH (P=0.002) were positively associated with Japanese stiltgrass abundance, while ammonium was negatively associated with Japanese stiltgrass abundance and seed production (P<0001) [152]. Studies in Maryland and Washington, DC, found higher levels of nitrogen and average levels of potassium and phosphorus on Japanese stiltgrass-infested soils compared to soils without Japanese stiltgrass [187]. In red maple forests of Arkansas, Japanese stiltgrass was positively correlated with high concentrations of soil boron (r=0.3) and zinc (r=0.5). In mixed-hardwood and oak-hickory forests of West Virginia, soils of interior plots with Japanese stiltgrass had significantly lower total carbon levels than plots without Japanese stiltgrass (P=0.07) [95]. In mixed-hardwood forests of New Jersey, however, sites where soils had high organic matter content were more susceptible to Japanese stiltgrass invasion than sites with low organic matter content [198].

Elevation and aspect: Japanese stiltgrass occurs from sea level up to 4,000 feet (1,000 m) elevation [59,136]. It is most common in low-elevation woodlands in the mid-Atlantic states and in the Piedmont and Appalachian mountains [182]. As of this writing (2010), it was not reported from high-elevation red spruce-Fraser fir (*Picea rubens-Abies fraseri*) forests. In mixed-hardwood communities in the Blue Ridge Mountains of North Carolina, Japanese stiltgrass was negatively correlated with high elevation ($P<0.05$) [115].

Few studies had been conducted on possible aspect preferences of Japanese stiltgrass as of 2010. In the Green Ridge State Forest, Maryland, Japanese stiltgrass presence was significantly positively associated with southwest ($P<0.001$) and northwest ($P<0.05$) aspects [143]. Japanese stiltgrass transplanted into canopy gaps in a New Jersey boxelder-green ash-sycamore forest showed better growth on the west side of the gaps compared to the east side [13].

Climate: Japanese stiltgrass grows in temperate to warm continental climates. In North America, the coldest reported winter temperatures that Japanese stiltgrass survives are approximately -5.8 to -9.4 °F (-21 to -23 °C) [187].

SUCCESSIONAL STATUS:
Japanese stiltgrass is a shade-tolerant grass that may occupy all stages of forest succession (review by [134]).

Little English-language literature on succession in plant communities where Japanese stiltgrass is native was available as of 2010. In Japan, Japanese stiltgrass and other annual grasses typically dominate warm-temperate Chino bamboo (*Pleioblastus chino*) grasslands that are in early succession [154].

The following discussion applies only to plant communities in the eastern and southeastern United States.

Early succession: Japanese stiltgrass generally obtains greatest cover on open, seral sites or in canopy gaps [59,191] (see Late succession for information on canopy gaps). Open, early-seral sites in which it has established include old fields [7,72], active floodplains [12], minespoils [183], hurricane-disturbed sites [214], plantations [159], thinned [7] or clearcut [12] forests, burned woodlands and forests ([7,12], Shimp 2002 personal communication in [72]), and especially, forest edges [30,187]. In Great Smoky Mountains National Park, for example, Japanese stiltgrass was most invasive on forest edges [5]. In the Oak Ridge National Environmental Research Park, Tennessee, Japanese stiltgrass seedling survivorship averaged 100% in full sunlight; 90% in 40% sunlight; 30% in 16% sunlight; and 5% in 6% sunlight. Biomass gain over the May to October growing season was significantly greater at 100% sunlight than at lower light levels ($P<0.001$). The forest overstory was dominated by sycamore, boxelder, and black walnut [38]. On abandoned surface coal mines in Kentucky, Japanese stiltgrass was the most important understory herb in early succession of a mixed-hardwood, mesophytic forest, forming 9% to 35% cover. It formed thick swards in open areas [183]. In mixed-hardwood and oak-hickory forests of West Virginia, Japanese stiltgrass presence was associated with several indicators of early forest succession, including open canopies ($P<0.001$), high moss (Bryopsida) cover ($P<0.001$)), shallow litter ($P=0.15$) cover, and low levels of coarse woody debris ($P=0.003$) [95].

Dry climate may favor Japanese stiltgrass invasion in old fields of the eastern Unites States. On old fields in the Hutcheson Memorial Forest, New Jersey, Japanese stiltgrass cover increased after a severe drought in 1999, when April and May rainfall was less than half of normal. Across plots, Japanese stiltgrass increased in total cover from a predrought level of 0.01% in 1997 to a postdrought level of 646.6% in 2001. During that time, Japanese stiltgrass increases in cover and frequency were greater than those of any other species in the old fields [250]. Since then, Japanese stiltgrass has become the dominant groundlayer species in Hutcheson Memorial Forest (Yurkonis 2006 personal observation cited in [250]).

Disturbance ecology: Japanese stiltgrass readily establishes following disturbances such as flooding, mowing, and tilling. Within 3 to 5 years, it may form monotypic stands that crowd out native vegetation [209,233]. A survey (based on herbaria collections and remote-sensing data) of weed invasion patterns in West Virginia showed that Japanese stiltgrass was most common in roadside and streamside vegetation [91].

Japanese stiltgrass can recover rapidly—and may increase—after flooding (but see Gibson and others [72]). The input of silt and nutrients that accompanies short-term flooding can promote Japanese stiltgrass growth. For example, a study was initiated in 1982 on the Big Cross Creek floodplain of North Carolina. Big Cross Creek flooded in 1983, temporarily reducing Japanese stiltgrass cover, but Japanese stiltgrass exceeded preflood cover within 2 years [12].

Japanese stiltgrass cover before and after flooding in North Carolina [12]

1982 (preflood)	1983 (postflood)	1985 (postflood)
48%	23%	55%

In a boxelder-white ash-sycamore floodplain community in North Carolina, Barden [12] concluded that a history of disturbance was likely to improve Japanese stiltgrass's ability to invade a site. A relatively deep litter layer, greater LAI of other ground-dwelling species compared to Japanese stiltgrass, and high levels of sunlight reduced reproductive success of Japanese stiltgrass. He found that soil fertility was relatively unimportant in determining invasive ability of Japanese stiltgrass. Japanese stiltgrass failed to regenerate on undisturbed, fertile plots (high levels of soil nitrogen, potassium, calcium, and zinc). Japanese stiltgrass showed greater biomass gain on plots treated with fertilizer compared to unfertilized control plots, but seed spikelet production was similar on fertilized vs. unfertilized plots [12].

It is unclear how vulnerable undisturbed sites are to Japanese stiltgrass invasion, and what factors, if any, contribute to a site's invasibility. Anecdotal evidence suggests that Japanese stiltgrass may not invade, or is slow to invade, undisturbed sites. However, long-term studies are needed to document Japanese stiltgrass's rate of colonization and expansion onto disturbed sites. A fact sheet suggests that Japanese stiltgrass may slowly spread onto undisturbed lands unless control measures are taken [218]. Japanese stiltgrass was absent from unmowed land next to a sewer line right-of-way in North Carolina, but invaded annually mowed land near the right-of-way [12]. An inventory of Land Between the Lakes National Recreation Area, Kentucky and Tennessee, showed Japanese stiltgrass occurred both within and adjacent to the Recreation Area boundaries. It was more common on adjacent private lands than inside the Recreation Area, which has been protected from mining, logging, and grazing since 1963. The authors cautioned, however, that periodic flooding left the Recreation Area vulnerable to Japanese stiltgrass seed dispersal and invasion [126]. A review suggests that Japanese stiltgrass can spread rapidly onto undisturbed sites from adjacent disturbed sites where it is well established [233]. In a New Jersey survey, Japanese stiltgrass and garlic mustard were the only 2 nonnative species that invaded undisturbed chestnut oak-red oak-pitch pine stands [16].

Midsuccession: Japanese stiltgrass is common in midsuccessional forests. In the Green Ridge State Forest, Maryland, Japanese stiltgrass presence was positively associated ($P<0.05$) with moderate (26-50%) canopy openings [143]. In Great Smoky Mountains National Park, mean height of Japanese stiltgrass stands peaked at 30% to 40% sunlight and decreased slightly after that. However, biomass of individual Japanese stiltgrass plants increased linearly with percent sunlight ($P<0.001$) [243]. In Maryland, Japanese stiltgrass infestations were common on shaded roadsides but not open roadsides [187].

Late succession: Japanese stiltgrass is shade tolerant [47,59,90] and can persist in late-successional forests as the canopies close [5,90,187,199]). In mixed-hardwood communities in the Blue Ridge Mountains of North Carolina, Japanese stiltgrass presence was positively correlated with forest cover ($P<0.05$) [115]. Japanese stiltgrass may form patches or dense, continuous lawns in late-successional forests [54]. An invasive species guide reports Japanese stiltgrass can persist in <5% sunlight [237]. Cheplick [30] reported Japanese stiltgrass on edges and under completely closed canopies of sweetgum-sycamore and loblolly pine-white oak-sweetgum forests of Mississippi, and Japanese stiltgrass was an understory component in old-growth sweetgum-overcup oak (*Quercus lyrata*)-river birch bottomland forests of Tennessee [200].

In late succession, Japanese stiltgrass usually occurs in canopy gaps. In a bottomland box elder-yellow-poplar-sycamore forest in Indiana, Japanese stiltgrass was positively correlated with light availability ($r^2=0.49$, $P=0.04$) [65]. Hemlock wooly adelgid infestations [57,58] or other canopy-opening events may provide favorable open sites for Japanese stiltgrass invasion. In Connecticut eastern hemlock forests with high mortality from hemlock wooly adelgids, several nonnative species showed high cover including Japanese stiltgrass, Oriental bittersweet, Japanese barberry, and tree-of-heaven [157]. In mixed-hardwood forests of North Carolina, vegetation frequency was surveyed on 107 permanent plots established in 1977 and resurveyed in 2000. Japanese stiltgrass had the second-highest increase in overall frequency during those 23 years; native American pokeweed (*Phytolacca americana*) increased most in frequency. Japanese stiltgrass was particularly abundant in open forest patches created by Hurricane Fran [214]. Based on field experiments, Cheplick [31] reported that Japanese stiltgrass may persist or spread in late-successional hardwood communities where sunflecks reach photosynthetic Japanese stiltgrass tissue.

Apparently, Japanese stiltgrass does not typically invade closed-canopy forests lacking canopy gaps [199]. Field experiments in Kentucky showed Japanese stiltgrass was unable to establish under the subcanopy, which consisted of juvenile red maple and spicebush. The oak-hickory forest was in late succession, and PAR was 1% to 2.5% of full sunlight beneath red maple and spicebush (abstract by [39]).

Japanese stiltgrass may alter successional pathways of forests in mid- to late succession. It grows quickly; Japanese stiltgrass is soon taller than the seedlings of most associated woody species and likely outcompetes young, native woody species and herbs for light [5]. In an oak-beech-maple forest of Lilly-Dickey Woods, Indiana, Japanese stiltgrass gained significantly more aboveground biomass than the native grass deertongue (*Dichanthelium clandestinum*) in fully shaded sites, while deertongue gained more biomass than Japanese stiltgrass in full sunlight ($P<0.001$). Biomass of the 2 grasses was similar in partial shade [64]. Japanese stiltgrass may establish in gaps that were historically colonized by oaks, hickories, ashes, and other early-seral tree species [171]. Aronson [8] speculated that in young-secondary oak forests, environmental changes associated with Japanese stiltgrass invasion, such as increased soil pH and soil nitrogen, may facilitate invasion of other nonnatives. On the Hutcheson Memorial Forest, New Jersey, Japanese stiltgrass was negatively correlated with cover of other nonnative species in young-secondary white oak-black oak-red oak forests. However, in mature-secondary and old-growth white oak-black oak-red oak forests, Japanese stiltgrass presence was positively correlated with cover of other nonnative species ($P<0.05$ for all variables). Young-secondary, mature-secondary, and old-growth forests were 50, 150, and ~300 years old, respectively. Overall, Japanese stiltgrass and garlic mustard were the dominant groundcover species at Hutcheson Memorial Forest. From 1950 to 1979, importance value of Japanese stiltgrass was 0, but it jumped to 32 by 2003 [8]. See the Impacts section for more information on other examples of Japanese stiltgrass's potential to alter forest succession.

White-tailed deer and Japanese stiltgrass may synergistically alter successional pathways in eastern deciduous forests with dense white-tailed deer populations [10]. See Impacts for more information on this relationship.

FIRE EFFECTS AND MANAGEMENT

SPECIES: Microstegium vimineum

FIRE EFFECTS:

Immediate fire effect on plant: As of this writing (2010) there were few accounts in the literature regarding the effects of fire on Japanese stiltgrass, and available information was mostly anecdotal. As an annual, Japanese stiltgrass is likely killed by mid- to late-season fires [12], although spring [59,218] and summer [218] fire may only top-kill Japanese stiltgrass. Accounts of postfire establishment provided by Barden [12] and Shimp (personal communication cited in [72]) suggest that Japanese stiltgrass seeds in the soil seed bank are likely to survive fire. However, information on the fire ecology of Japanese stiltgrass is limited, and research is needed to clarify fire effects on Japanese stiltgrass.

Postfire regeneration strategy [204]:
Caudex or an herbaceous root crown, growing points in soil
Stolons in organic soil or on soil surface
Ground residual colonizer (on site, initial community)
Initial off-site colonizer (off site, initial community)
Secondary colonizer (on- or off-site seed sources)

Fire adaptations and plant response to fire:

Fire adaptations: As an annual, Japanese stiltgrass likely relies mostly on postfire establishment from either on-site, soil-banked seed or off-site, transported seed. Limited studies [6,7,73] and anecdotal accounts [12,72,207] of postfire Japanese stiltgrass establishment appeared in the literature; however, details were few. Japanese stiltgrass spread after litter removal down to mineral soil or litter removal and mineral soil disturbance in Tennessee [130], and it may establish from seed on mineral soil after fire [59]. In at least one account, Japanese stiltgrass likely established from soil-stored seed following a "hot" surface fire [12] (see Plant response to fire). Given its ability to store seed in the soil seed bank, effectively disperse seed, and establish on open, disturbed sites (see Successional Status), Japanese stiltgrass is likely to persist or invade after fire.

Plant response to fire: Although details were lacking in available literature (2010), this annual grass must establish mostly from soil-stored seed and/or off-site seed transported onto burned sites. A review by Tu [218] suggests that following early-season fire, top-killed Japanese stiltgrass may sprout and set seed later in the year (see Seasonal Development). According to a management guide for the southern United States [59] and Tu [218], Japanese stiltgrass that has not yet flowered may sprout from tillers and stolons following top-kill by fire [218]. Japanese stiltgrass may also establish from on- or off-site seed sources following fire ([7,12,72], review by [134]); a second crop of seedlings may establish after spring fire [12]. A review indicated that exposed mineral soils, such as those occurring after fire, provide a favorable seedbed for Japanese stiltgrass germination and establishment [238].

Japanese stiltgrass benefits from disturbances that open the canopy (see Successional Status); this likely includes fire [72]. A few studies demonstrate Japanese stiltgrass's ability to establish in postfire environments.

In the Vinton Furnace Experimental Forest, Ohio, oak-hickory and sugar maple-sweetgum-yellow-poplar communities, mechanical litter removal, prescribed fires (both low and moderate severity) increased Japanese stiltgrass seedling establishment and growth compared to control plots ($P<0.05$ for all variables) [73]. Study plots were sown with Japanese stiltgrass seeds in postfire year 1, after burning. Japanese stiltgrass was removed prior to seed set to prevent invasion beyond study plots. In postfire year 2, seeds were sown in different burned plots that had previously been sown with multiflora rose but not Japanese stiltgrass. On burned plots, Japanese stiltgrass stem height and leaf number were greatest in canopy gaps on moderate-severity plots ($P<0.05$). August surveys revealed year and site interactions in Japanese stiltgrass's response to prescribed fire. In postfire year 1, Japanese stiltgrass seedling establishment was greatest on burned or litter-removed plots ($P<0.0001$). In postfire year 2, seedling establishment was greater in valley plots, where sugar maple tended to dominate, than on ridges, where oaks tended to dominate ($P<0.01$) [73]. The authors concluded that prescribed fire created a disturbance suitable to Japanese stiltgrass invasion ([73], abstract by Glasgow and Matlack [74]), and litter removal was the mechanism by which fire enhanced Japanese stiltgrass seedling recruitment [73]. See the Research Project Summary of this study for details on the fire prescription, fire behavior, and postfire responses of Japanese stiltgrass and multiflora rose.

Japanese stiltgrass invaded a remnant prairie after thinning and prescribed burning on the LaRue-Pine Hills Research Natural Area, Illinois [6,7]. See Preventing postfire establishment and spread for details.

There are several anecdotal accounts of postfire Japanese stiltgrass recruitment. In a boxelder-white ash-sycamore floodplain community in North Carolina, a 9 April 1982 prescribed fire entered a dense upland stand of Japanese stiltgrass seedlings. The previous year's cohorts had left a dense mat of Japanese stiltgrass litter that fueled "a hot ground fire" that killed the seedlings. By mid-June, a second cohort of Japanese stiltgrass had established, presumably from soil-stored seed, and provided dense ground cover [12]. Gibson and others [72] reported "increased recruitment" of Japanese stiltgrass following prescribed fire in a xeric, early-successional oak-hickory woodland that established on old fields abandoned in the 1960s (Shimp personal communication cited in [72]). In black oak-blackjack oak-post oak forests of northern Mississippi and western Tennessee, Surrette [207] found that Japanese stiltgrass was more abundant on spring-burned (March-April) plots compared to unburned plots. The author speculated that Japanese stiltgrass cover increased because the prescribed burning immediately preceded the time of Japanese stiltgrass germination [207].

FUELS AND FIRE REGIMES:

- **Fuels**
- **Fire regimes**

Fuels: Live Japanese stiltgrass may be difficult to burn, however. Its low flammability and relative unpalatability suggest that it has high silica content, which could reduce its ability to carry fire when green [236].

As of 2010, measurements of Japanese stiltgrass fuel loads in northeastern or southeastern forests were not available in the literature. Japanese stiltgrass's ability to exclude woody species and form thick ground cover suggest that it may increase fine fuels and reduce woody debris from historical levels. However, Kourtev and others [111] reported that in New Jersey, sites invaded by Japanese stiltgrass had thinner litter and organic soil layers than sites without Japanese stiltgrass, which they attributed to high densities of nonnative earthworms on sites with Japanese stiltgrass (see Soil and soil microfauna changes for more information). Similarly, in white oak forests of New York, Japanese stiltgrass-invaded sites had thinner organic soil horizons than adjacent uninvaded sites [54]. Additionally, Japanese stiltgrass litter tends to decay slowly, which may increase fine fuels compared to sites with litter of faster-decaying native species.

As an annual, mat-forming grass, Japanese stiltgrass often produces large amounts of fine litter that may remain on the forest floor longer than litter of some native plant species. Japanese stiltgrass stems lodge soon after they die in autumn [12,28]. When thick, they create a continuous fuelbed of matted straw that could potentially fuel a surface fire [12]. Japanese stiltgrass litter apparently decays more slowly than litter of some associated species [43]. In a New Jersey study, Japanese stiltgrass litter decayed more slowly than litter of native hillside blueberry [56]. In a North Carolina field experiment, litter of nonnative Oriental lady's-thumb (*Polygonum caespitosum*) was about 30% decayed after 120 days, while Japanese stiltgrass was only about 5% decayed [43,45]. However, in a landscape-level study of 3 white oak-sweet birch forests in New Jersey, sites with Japanese stiltgrass had less litter than adjacent uninvaded sites. Over 2 years, the on-site decay rate of white oak litter was slower (30% mass loss) than decay rates for Japanese stiltgrass litter (40%-50%) [54].

Dibble and others [47] reported that standing dead and down litter of Japanese stiltgrass and other nonnative invasive grasses may present a fuel hazard in drought years. Flammability of live Japanese stiltgrass, however, may be low. In the laboratory, Japanese stiltgrass's heat of combustion was among the lowest of 42 native and nonnative species in the Northeast [48]. A management guide for the southern United States reports that Japanese stiltgrass is not a fire hazard [59].

In mixed-hardwood and oak-hickory forests of West Virginia, interior forest plots with Japanese stiltgrass had significantly lower coarse woody debris cover than plots without Japanese stiltgrass ($P<0.003$) [95].

Fire regimes: Across Japanese stiltgrass's US distribution, fire regimes vary from frequent surface fires to long-interval, stand-replacement fires. In northeastern maple-birch-beech (*Acer-Betula-Fagus* spp.) forests, historic fire-return intervals were highly variable, depending upon microclimate, topography, and soil. Fires were mostly of mixed severity. Stand-replacing, medium-interval (~80-yr) fires were most common in forests dominated by birches, while long-interval (≥300 years), mixed-severity or stand-replacing fires occurred in forests dominated by maple and/or beech [60,69,83,195,234]. Oak-hickory, oak-pine, and pine forests of the Northeast and Southeast had mostly frequent understory surface fires [208,234]. See the Fire Regime Table for further information on fire regimes of vegetation communities in which Japanese stiltgrass may occur.

Japanese stiltgrass was not present in these forests while historic fire regimes were still operating, and it is unclear how Japanese stiltgrass may affect or alter fire regimes in plant communities where it is present. Japanese stiltgrass's tendency to invade disturbed forests (see Successional Status), its ability to produce abundant litter that decays slowly, and its potential to reduce establishment of woody species and form monocultures—thereby altering stand structure (see Impacts)—make it likely that Japanese stiltgrass may alter fuel loads and fire behavior from historic patterns. Further fire studies on Japanese stiltgrass and observations of fire behavior where Japanese stiltgrass is present are needed.

FIRE MANAGEMENT CONSIDERATIONS:
In general, diligent monitoring and early detection are critical for preventing establishment of large populations of invasive plants. Eradicating established Japanese stiltgrass plants and small patches adjacent to a burned area may prevent or limit seed dispersal into the burn [9,78,224].

Potential for postfire establishment and spread: Japanese stiltgrass's autecology suggests that it is likely to invade burns. It favors disturbed, open sites and mineral soil for establishment (see Regeneration Processes) and once present, tends to displace native vegetation (see Impacts). Postfire establishment is especially likely on burns subject to foot, motor vehicle, and other traffic that can transport Japanese stiltgrass seeds onto the burn (see Seed dispersal). Romanello [191] reported that Japanese stiltgrass was most likely to establish from the soil seed bank if present before disturbance, suggesting postfire Japanese stiltgrass establishment can be expected where Japanese stiltgrass was present before fire. Based on reports to date (2010), groundlayer dominance of Japanese stiltgrass has been greatest in yellow-poplar-sweetgum communities; however, given Japanese stiltgrass invasion and spread in a wide range of forest and some shrubland and grassland types in the eastern and southern United States (see Habitat Types and Plant Communities), most low- to midelevation sites can be considered vulnerable to postfire Japanese stiltgrass invasion.

Preventing postfire establishment and spread: Preventing Japanese stiltgrass and other invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. This may be accomplished through early detection and eradication, careful monitoring and follow-up, and limiting dispersal of invasive plant propagules into burned areas. General recommendations for preventing postfire establishment and spread of invasive plants include:

- Incorporate cost of weed prevention and management into fire rehabilitation plans
- Acquire restoration funding
- Include weed prevention education in fire training
- Minimize soil disturbance and vegetation removal during fire suppression and rehabilitation activities
- Minimize the use of retardants that may alter soil nutrient availability, such as those containing nitrogen and phosphorus
- Avoid areas dominated by high priority invasive plants when locating firelines, monitoring camps, staging areas, and helibases
- Clean equipment and vehicles prior to entering burned areas
- Regulate or prevent human and livestock entry into burned areas until desirable site vegetation has recovered sufficiently to resist invasion by undesirable vegetation
- Monitor burned areas and areas of significant disturbance or traffic from management activity
- Detect weeds early and eradicate before vegetative spread and/or seed dispersal
- Eradicate small patches and contain or control large infestations within or adjacent to the burned area
- Reestablish vegetation on bare ground as soon as possible
- Avoid use of fertilizers in postfire rehabilitation and restoration
- Use only certified weed-free seed mixes when revegetation is necessary

For more detailed information on these topics, see the following publications: [9,23,78,224].

Japanese stiltgrass may require postfire control on sites where thinning and prescribed fire promoted its germination and spread. The LaRue-Pine Hills Research Natural Area of southern Illinois is a remnant little bluestem-indiangrass (*Schizachyrium scoparium*-*Sorghastrum nutans*) prairie barren that was historically maintained by frequent fires. The fires, probably intentionally set by Native Americans [1,42,70,71,210], maintained the barren by pruning woody vegetation to a bushy, scrub form. Forest Service personnel intermittently managed the Research Natural Area with fire from 1969 to 1993. That period included 16 years of fire exclusion (1974-1989), during which woody vegetation began invading the barrens. Restoration thinnings of white oak, southern red oak, common persimmon, and other woody species began in 1988. Annual prescribed burning was resumed in 1990. Japanese stiltgrass was first noted on woodland study plots in 1992 but was not found on similarly treated barren or woodland-barren transition area plots. The authors suggest that Japanese stiltgrass "was likely favored by the disturbance associated with mechanical removal of woody species and the reintroduction of prescribed burning" in the woodland [6,7].

Use of prescribed fire as a control agent: To date (2010), the available literature provided no accounts of successful control of Japanese stiltgrass using prescribed fire; however, there may potential for using prescribed fire to control Japanese stiltgrass under some circumstances and in combination with other treatments. For example, burning might be used to help reduce litter and standing plant biomass prior to herbicide application for Japanese stiltgrass control [218], although there is some question about whether Japanese stiltgrass will carry fire when green (see Fuels). Early-season fire does not control Japanese stiltgrass (Barden 1991 as cited by [218]); burned plants may sprout and seedlings may establish from soil-stored seed and produce new seed by the end of the growing season. Fall fire, when Japanese stiltgrass is flowering but before seed set (see Seasonal Development), may help control Japanese stiltgrass

[218].

In Big Oaks National Wildlife Refuge, Indiana, late summer prescribed fire, spring prescribed fire, hand-pulling, and fall mowing were compared as control treatments for Japanese stiltgrass. Study sites were in second-growth American beech-black walnut-Virginia pine/northern spicebush forest with a history of prescribed fire. Late summer fires were ignited and mowing was conducted in early September after Japanese stiltgrass had set seed. Spring fires were ignited and hand-pulling started in June, when Japanese stiltgrass seedlings were 4 to 8 inches (10-20 cm) tall. Compared to untreated control plots, fall fire and mowing caused significant reductions in Japanese stiltgrass cover and biomass. Compared to controls, fall fires reduced Japanese stiltgrass cover by 79% and biomass by 90%, while mowing reduced cover by 70% and biomass by 95%. Spring fire significantly reduced Japanese stiltgrass cover but not its biomass ($P<0.05$ for all variables). Hand-pulling in spring did not significantly change Japanese stiltgrass cover or biomass. Native understory species showed no significant difference in cover or biomass on treated compared to control plots [68].

Altered fuel characteristics: Japanese stiltgrass has the potential to increase litter, reduce woody debris, and alter stand structure where it is present. See Fuels and Impacts for further details.

MANAGEMENT CONSIDERATIONS

SPECIES: Microstegium vimineum

- FEDERAL LEGAL STATUS
- OTHER STATUS
- IMPORTANCE TO WILDLIFE AND LIVESTOCK
- OTHER USES
- IMPACTS AND CONTROL

FEDERAL LEGAL STATUS:
None

OTHER STATUS:
Information on state-level noxious weed status of plants in the United States is available at Plants Database. The Eastern Region of the U.S. Forest Service lists Japanese stiltgrass as a Category 1 noxious weed: a nonnative, highly invasive plant that invades natural habitats and replaces native species [222].

IMPORTANCE TO WILDLIFE AND LIVESTOCK:
Japanese stiltgrass is unpalatable to deer and livestock [136]. White-tailed deer do not usually graze it, and they may indirectly encourage Japanese stiltgrass spread by avoiding it and foraging on more palatable species [57,209]. In an oak-sugar maple forest in southern Connecticut, white-tailed deer consumed Japanese stiltgrass incidentally but preferred native grasses and forbs [244]. In eastern hemlock forests in the Delaware Water Gap National Recreation Area, Pennsylvania and New Jersey, Japanese stiltgrass cover increased proportionally with white-tailed deer density [57]. In a red maple-yellow-poplar-white oak cover forest in Great Smoky Mountains National Park, Tennessee, Japanese stiltgrass was the dominant groundlayer species. Cover of Japanese stiltgrass was almost twice that on plots open to white-tailed deer compared to exclosure plots ($P=0.059$) [80].

Insects graze Japanese stiltgrass, although the extent of their use was largely unstudied as of 2010. In a red maple-white oak-sycamore forest in the Whitehall Experimental Forest, Georgia, some genera of short-horned grasshoppers, katydids, crickets, and bugs obtained a substantial fraction (35-100%) of their diet from Japanese stiltgrass. Sample sizes ranged from 1 to 10 individuals per insect genus. Insect guilds using in early-successional forests may be more likely to use Japanese stiltgrass than insects using forests in later seres. In this study, invertebrates in canopy gaps (where Japanese stiltgrass forage is usually most abundant) tended to actively avoid capture and were mostly green, while invertebrates under closed canopies tended to remain still when detected and had cryptic coloration [20].

Nutritional value: No information was available on the nutritional content of fresh Japanese stiltgrass forage. Strickland and others [206] provide information on the nutritional content of Japanese stiltgrass litter.

Cover value: Japanese stiltgrass may provide important cover for white-footed mice. In loblolly pine-Virginia pine forests of Virginia, white-footed mice were more abundant on plots with than without Japanese stiltgrass. The author suggested that sites with Japanese stiltgrass may provide more nesting sites, nesting materials, and/or have decreased predation rates than sites without Japanese stiltgrass. White-footed mice were observed navigating through dense Japanese stiltgrass culms without difficulty, although they avoided areas with dense cover of native little bluestem (*Schizachyrium scoparium*). Among 6 other small mammal species, none were either positively or negatively associated with Japanese stiltgrass [235].

Japanese stiltgrass may reduce suitable cover and habitat quality for the federally threatened [226] bog turtle on old-field or resting pastures. In surveys of potential bog turtle habitats in New Jersey and New York, Japanese stiltgrass was present in <10% of wetland plots with bog turtles. On those plots, Japanese stiltgrass was significantly taller (3 feet (0.9 m)) in wetlands that dairy cattle had formerly grazed compared to its height in ungrazed wetlands (1 foot (0.3 m)) ($P<0.01$). Its cover was also greater in formerly grazed (3.9%) than in ungrazed (2.0%) wetlands, although the difference was not statistically significant. Overall, height of herbaceous species was lower and native species diversity higher on formerly grazed than ungrazed wetlands, and significantly more bog turtles were captured on formerly grazed than ungrazed wetlands ($P=0.001$) [215].

Japanese stiltgrass may reduce habitat quality of some tick species. In Indiana, experimentally introduced lone star ticks (*Amblyomma americanum*) and dog ticks (*Dermacentor variabilis*) showed higher mortality rates in Japanese stiltgrass-invaded plots than in plots without Japanese stiltgrass. In Japanese stiltgrass plots, mortality of lone star ticks and dog ticks increased 173% and 70%, respectively, compared to mortality in uninvaded plots. The authors attributed the higher death rates in Japanese stiltgrass plots to increased temperatures and decreased humidity at the soil surface and in litter compared to uninvaded plots [34].

OTHER USES:
Japanese stiltgrass was once used as packaging material and as basket-weaving material. Both historic uses probably contributed to its spread in the United States. It is not used for erosion control, as forage, or as an ornamental [218].

IMPACTS AND CONTROL:
Impacts:
Invasiveness: Japanese stiltgrass can be highly invasive on disturbed sites [16]. Unpublished surveys from 1992 showed Japanese stiltgrass was the most frequently reported nonnative, invasive annual grass in The Nature Conservancy's US preserves [184]. Characteristics that contribute to Japanese stiltgrass invasion include [35,218]:

- rapid invasion of disturbed habitats
- annual life history
- reproductive plasticity in the face of varying environmental conditions
- high seed production
- rapid clonal growth

Compared to uninvaded sites, sites where Japanese stiltgrass is prevalent may show reduced ecosystem function and, on silvicultural sites, timber production may be less.

A 2003 review of vegetation surveys in the eastern United States revealed that Japanese stiltgrass was among the most commonly reported invasive species, and it was the most common invasive annual grass. It was most frequent on floodplains and in mesic forests [125]. It was ranked a high invasive threat in deciduous, coniferous, and mixed forests, grasslands, old fields, riparian zones, and fresh wetlands of the Northeast [49], and it was ranked a high to moderately-high threat in red oak and eastern hemlock forests of Delaware Water Gap National Recreation Area [93]. As of 2000, the density of Japanese stiltgrass infestations in Dixon State Park, Illinois, ranged from 2.3 stems/m² to 16,706 stems/m² [72].

Surveys show that as of 2008, Japanese stiltgrass occupied about 650,000 acres (260,000 ha) in the Southeast [138], and it was most invasive in Tennessee, North Carolina, and northwestern South Carolina [137]. It is ranked a high invasive threat in upland grasslands and oak-hickory woodlands and a potentially high threat in wet grasslands and palmetto (Arecacae) prairies [205]. In the southern Appalachian region, 8 of 35 federal, state, and private agencies ranked Japanese stiltgrass among their greatest ongoing or potential management problems (behind kudzu (*Pueraria montana* var. *lobata*) and multiflora rose) [117]. It was the most frequent (23%) of any nonnative species found in a 2006 survey of riparian forests in North Carolina [231]. Surveys in mixed-hardwood communities in the Blue Ridge Mountains of North Carolina also found Japanese stiltgrass was the most frequent nonnative invasive species, occurring in 100% of watersheds and 84% of plots [115]. In Oak Ridge National Environmental Research Park, Tennessee, Japanese stiltgrass was ranked the most "aggressively invasive" nonnative species based on distribution, abundance, relative difficulty of control, and ability to exclude native plant species. Japanese honeysuckle and Chinese privet were ranked 2nd and 3rd, respectively [50]. Japanese stiltgrass reportedly replaced existing ground vegetation in 3 to 5 years on sites in Great Smoky National Park [203], and it has formed "extensive and dense" infestations in Natural Areas and Parks, managed forests, wetlands, riparian areas, and rights-of-way in Alabama and adjacent states [4].

Because Japanese stiltgrass is an annual, its productivity is more closely tied to yearly climate fluctuations than that of perennial herbaceous species. Annual variations in Japanese stiltgrass productivity can have important effects on forest understory species composition and diversity. On a sweetgum site on the Oak Ridge National Environmental Research Park, Japanese stiltgrass produced 64% as much biomass in a wet year compared to a dry year [19]. Using a model, Holcombe [87] predicts a gain of 51,400 miles² (133,000 km²) in Japanese stiltgrass cover in North America due to climate change.

Ecosystem function: Japanese stiltgrass is associated with changes in ecosystem function, including altered soil characteristics, changes in soil microfaunal composition, lowered plant and animal species diversity, and altered stand structure. These changes may interfere with growth and establishment of native and other invasive nonnative species. Japanese stiltgrass has also been implicated as being allelopathic. Sites with Japanese stiltgrass may also have less coarse woody debris and more fine fuels than uninvaded sites; this is discussed in Fuels.

- Soil and soil microfauna changes
- Diversity and stand structure
- Interference
- Allelopathy

Soil and soil microfauna changes: Japanese stiltgrass may alter ecosystem function on forest floors and in forest soils [54,56,110,111,112,113,114] by affecting litter layers, soil composition, and species composition of soil microfauna. For example, Kourtev and others [111] reported that Japanese stiltgrass-invaded areas in New Jersey had thinner litter and organic soil layers than sites without Japanese stiltgrass; they attributed these changes to high densities of nonnative earthworms on sites with Japanese stiltgrass. Sites invaded by Japanese stiltgrass have also shown lower levels of soil carbon, nitrogen, and net ammonification [113]; dissimilar soil enzymes; and had significantly higher soil pH compared to uninvaded areas [110,112,114,133]. In white oak forests of New York, Japanese stiltgrass-invaded sites had thinner organic soil horizons, higher soil pH values, and higher levels of available soil nitrate compared to adjacent uninvaded sites [54]. In a chestnut oak-black oak-red maple forest, an eastern white pine plantation, and an old field in Tennessee, soil beneath Japanese stiltgrass litter had significantly higher pH and phosphorus levels and lower aluminum levels than soil beneath litter from uninvaded plots, regardless of plant community type. Overall, soil invertebrate richness was lower in Japanese stiltgrass litter than in uninvaded litter in all community types, although Japanese stiltgrass litter housed more mite species than litter from uninvaded plots. The authors surmised that in Japanese stiltgrass litter, overall diversity of forest-floor invertebrates may decrease, but mite populations may increase [133]. In white oak and American beech forests of New Jersey, soil microbial communities differed in species composition in Japanese stiltgrass-invaded and uninvaded areas, and nonnative earthworms were more common on Japanese stiltgrass sites compared to uninvaded sites [111,113]. Kourtev and others [110] warn that such drastic changes to soils will likely persist and may encourage reinvasion by Japanese stiltgrass or invasions by other nonnative species.

Japanese stiltgrass may alter soil nutrient cycling [44,45,45,206], although some claim the already altered nutrient status of disturbed sites favors Japanese stiltgrass establishment [86]. In a North Carolina wetland undergoing restoration, sites dominated by Japanese stiltgrass appeared to have decreased nitrogen cycling compared to sites where Japanese stiltgrass was removed. Decomposition and nitrogen release from Japanese stiltgrass litter was about half that of litter of native groundlayer species, and species richness was significantly less on invaded plots compared to plots where Japanese stiltgrass was controlled [44,45]. DeMeester [45] concluded that compared to native species, Japanese stiltgrass "is clearly superior in capitalizing resources and suppressing other vegetation". In oak-pine forest in Whitehall Experimental Forest, Georgia, carbon apparently cycled of sites with Japanese stiltgrass than on sites without Japanese stiltgrass. Plots with Japanese stiltgrass showed reduced total organic carbon (24% decline, $P<0.09$), particulate organic matter (34% decline, $P<0.08$), mineralizable carbon (a measure of microbially-available carbon; 36% decline, $P<0.01$), and microbial-biomass carbon (72% decline, $P<0.05$). The authors suggested that Japanese stiltgrass may accelerate carbon cycling and deplete carbon levels in southern oak-pine forests [206]. In mixed-hardwood and oak-hickory forests of West Virginia, interior forest plots with Japanese stiltgrass had significantly lower soil carbon levels than plots without Japanese stiltgrass ($P=0.07$) [95].

Changes in soil chemistry and microfaunal composition associated with soil disturbances tend to favor Japanese stiltgrass. Across Fairfax County, Virginia, riparian sites in zones changing from rural to urban had increased sediment deposition, increased available soil phosphorus, and decreased soil nitrogen compared to rural riparian zones. In aboveground Japanese stiltgrass tissues, phosphorus content increased with urbanization, while the nitrogen:phosphorus ratio decreased. The authors suggested that disturbances and changes in soil nutrient levels enhanced the suitability of urbanizing riparian zones as Japanese stiltgrass habitat [86]. Nonnative earthworms may also favor Japanese stiltgrass invasion. In sugar maple and oak-hickory forests of New York and Pennsylvania, biomass of nonnative earthworm species was positively associated with Japanese stiltgrass and 2 other nonnative species, garlic mustard and Japanese barberry. Nonnative earthworm biomass was negatively correlated with leaf litter volume ($r = -0.58$, $P<0.001$) [155]. Several studies show that deep litter, which is more typical of early- than late-successional forests, discourages Japanese stiltgrass establishment [33,131,212] (see Germination and Seedling establishment and plant growth). Nuzzo and others [155] suggest that nonnative earthworm species, rather than Japanese stiltgrass, may be driving changes in ecosystem function—such as reduced native plant diversity—in forest communities of the eastern United States, and that nonnative earthworms may facilitate establishment of nonnative plant species.

Japanese stiltgrass may favor insect guilds that use the ground layer as habitat. In a harvested white oak-yellow-poplar forest in Tennessee, there was significantly greater cover of all insect guilds (herbivores, omnivores, carnivores, and scavengers) on sites with than without Japanese stiltgrass ($P\leq0.05$), probably because there was 2.5 times more plant cover on sites with Japanese stiltgrass. Measurements were taken at the end of the growing season (mid-October) [130].

Diversity and stand structure:
Plant species diversity: Sites with Japanese stiltgrass tend to have lower native and total plant species diversity than sites without Japanese stiltgrass [2,3,21,43,72,95,241]. In an oak-yellow-poplar forest in Tennessee, density ($r^2=0.80$, $P<0.001$) and diversity ($r^2=0.31$, $P=0.02$) of native woody species was less in Japanese stiltgrass-infested compared to uninfested sites. The authors suggested

that regeneration of woody species in southern forests will likely be reduced with Japanese stiltgrass invasion [162]. In a bottomland box elder-yellow-poplar-sycamore forest in Indiana, plots tilled and sown with native herbs and Japanese stiltgrass had significantly different groundlayer species composition than plots tilled and sown with only native herbs. Japanese stiltgrass plots showed 43% lower groundlayer species richness and 38% lower diversity than plots without Japanese stiltgrass. There was a strong negative correlation between Japanese stiltgrass presence and biomass of the sown native herbs ($P<0.0001$ for all variables) [65,67]. In urban riparian forests of North Carolina, Japanese stiltgrass presence was negatively correlated with presence of white oak, hickories, flowering dogwood, and mapleleaf viburnum (*Viburnum acerifolium*) ($P<0.05$). The authors found that light and high soil nutrient levels were positively associated with cover of nonnative species in general ($P<0.05$), and suggested that Japanese stiltgrass is competitively excluding woody species in urban riparian forests of the eastern United States [231]. In sweetgum-sycamore and loblolly pine-white oak-sweetgum forests of Mississippi, Japanese stiltgrass presence was significantly associated with low species richness, and Japanese stiltgrass production was less in species-rich plant communities than in species-poor communities ($P<0.001$) [21]. In mixed hardwood and oak-hickory forests of West Virginia, interior forest plots with Japanese stiltgrass had significantly lower herb, liana, and shrub diversity ($P=0.03$) and tree seedling richness ($P=0.02$) and diversity ($P=0.07$) than plots without Japanese stiltgrass [95]. In surveys within Chesapeake and Ohio Canal National Historic Park, Maryland, plots with Japanese stiltgrass had greater native species diversity than plots without Japanese stiltgrass until August, when Japanese stiltgrass overtopped associated groundlayer species. After that, native species diversity was greater on plots without than with Japanese stiltgrass [2,3].

Animal species diversity and stand structure: In areas with dense white-tailed deer populations, Japanese stiltgrass and white-tailed deer interactions may be altering forest structure, with attendant changes to wildlife populations. White-tailed deer avoid Japanese stiltgrass because it is unpalatable (see Importance to Wildlife and Livestock). Heavy white-tailed deer browsing of palatable woody species can result in dense cover of Japanese stiltgrass and little woody species regeneration [10,80,239]. Royo and Carson [194] termed this phenomenon a "recalcitrant understory"; such understories can persist for decades, altering forest structure and successional pathways. Baiser and others [10] postulated that in eastern deciduous forests, decreases in bird guilds that nest on the ground, the understory, or the midstory may be partially due to decline of under- and midstory woody species subject to heavy white-tailed deer browsing and replacement by Japanese stiltgrass. The authors found that from 1980 to 2005, breeding bird guilds using lower forest layers averaged greater population declines than bird species using the canopy for breeding, and the only bird species with increased populations were those nesting in the canopy. This general decline occurred for both resident and neotropical bird species that nest below the canopy. Among these guilds, eastern wood-pewees (midstory nester) and black-billed cuckoos (ground or understory nester) showed greatest declines in abundance [10].

Interference: Japanese stiltgrass may negatively impact establishment and growth of native species. For example, in hardwood floodplain forests of north-central Mississippi, Japanese stiltgrass interfered with growth of native slender woodoats (*Chasmanthium laxum*), whitegrass, and white oak seedlings. Density of the native species was negatively correlated with Japanese stiltgrass ($P\leq0.03$) [22]. It may interfere with production of forage species on rangelands [122].

Japanese stiltgrass may competitively exclude midstory species from germination and establishment sites. Based on germination and shade manipulation experiments conducted in a loblolly pine-red oak-black oak/flowering dogwood/mayapple (*Cornus florida/Podophyllum peltatum*) forest in Virginia, Shaw [199] suggested that Japanese stiltgrass may interfere with recruitment of midstory species such as eastern redbud (*Cercis canadensis*) and flowering dogwood (*Cornus florida*). There were significantly more eastern redbud (*Cercis canadensis*) germinants on plots without Japanese stiltgrass than on plots with Japanese stiltgrass ($P<0.001$). There were also more flowering dogwood germinants on plots without Japanese stiltgrass, but on all plots, recruitment of flowering dogwood was too scant for statistical analyses [199].

Silvicultural implications: Japanese stiltgrass is identified as a potentially serious competitor on productive timber sites in the Southeast [12,190,202]. It is implicated in reducing growth of timber species and associated species growing under the canopy. Because it is a tall grass that can form thick lawns, it often overtops and excludes native species. On the Hutcheson Memorial Forest, height of Japanese stiltgrass ranges from 10 to 40 inches (30-100 cm), far taller than most tree seedlings and forest herbs [8]. In red oak-green ash forests of New Jersey, survival of planted red oak and American ash seedlings was less on sites with Japanese stiltgrass than on sites where Japanese stiltgrass was removed ($P<0.0001$), but survival of associated red maple was not significantly affected by Japanese stiltgrass. Relative growth rates of red oak and American ash were significantly reduced on plots with Japanese stiltgrass ($P<0.0001$). Overall herbaceous species richness was less on plots with than on plots without Japanese stiltgrass ($P=0.02$). The author speculated that Japanese stiltgrass interference and white-tailed deer browsing (deer density range: 58-77/km^2) have a synergistic, negative effect on oak and ash regeneration in New Jersey forests [8] (see Animal species diversity for more information). On an oak plantation in southwestern Tennessee, Japanese stiltgrass presence was negatively correlated (r= -0.82) with growth of northern red oak seedlings. Four silvicultural treatments were tested: clearcut (all stems >6 inches (20 cm) diameter removed); 2-aged selection cut (harvest to retain a stand basal area of 15 to 20 $feet^2$/acre of residual oaks, hickories, and yellow-poplar); high-grade cut (all stems >14 inches (36 cm) DBH removed); and a control no-cut treatment. Mean biomass gain of Japanese stiltgrass was greatest with a 2-aged selection cut and least with the no-cut control [159]:

Japanese stiltgrass productivity (lb/acre) by silvicultural treatment in a Tennessee oak plantation [159]			

2-aged	Clearcut	High-grade	No cut
3,100	1,800	550	220

In a harvested white oak-yellow-poplar forest in Tennessee, Japanese stiltgrass mean stem length and number of nodes increased as canopy cover decreased, while soil temperature and moisture increased as Japanese stiltgrass cover increased. Leaf area of red maple and yellow-poplar was less in plots with than without Japanese stiltgrass, likely because Japanese stiltgrass outcompeted the hardwoods for soil moisture. Measurements were made at the end of the growing season (mid-October) [130].

Other nonnative species: Japanese stiltgrass may outcompete other nonnative herbs and woody species. Miller and others [138] compared the relative competitive abilities of Japanese stiltgrass and garlic mustard in greenhouse and field experiments. In the greenhouse, they found that in both shaded conditions and open sunlight, Japanese stiltgrass gained more aboveground biomass and had higher rates of photosynthesis than garlic mustard. In the field, Japanese stiltgrass seedlings also gained more biomass and had higher rates of photosynthesis than garlic mustard; additionally, it suffered less mortality and insect herbivory ($P<0.001$ for all variables). The authors concluded that in eastern forests, Japanese stiltgrass has greater potential than garlic mustard for spread on both open and shaded sites [138].

In a sweetgum plantation in Tennessee, Japanese stiltgrass outcompeted Japanese honeysuckle for light, gaining more height growth and biomass than and shading out Japanese honeysuckle when the two species were grown together. Watering increased Japanese stiltgrass's interference with Japanese honeysuckle growth. Since Japanese stiltgrass is an annual, Japanese stiltgrass's negative effect on Japanese honeysuckle growth may decrease as Japanese honeysuckle matures and gains height [18].

Allelopathy: In the laboratory, the inhibitory effect of Japanese stiltgrass extracts on germination of radish (*Raphanus sativus*) seed was strong enough ($\beta = -0.37$) that the authors suspected Japanese stiltgrass may be allelopathic. They called for field studies testing Japanese stiltgrass's possible allelopathy [178].

Control: Control of Japanese stiltgrass is difficult and requires multiple treatments [50]. In order to locally control this annual, seed-banking grass, repeated annual efforts must be made to prevent flowering and seed set until the seed bank is exhausted [72]. Japanese stiltgrass resembles native white grass, so proper identification of Japanese stiltgrass before control measures are undertaken is advised [136]. Shaw [199] writes that "*M. vimineum* is proving to be an enigma for scientists because it can grow and succeed in a wide range of habitats. This plasticity makes *M. vimineum* a difficult weed (in terms of preventing) its invasion and/or (controlling the) spread of existing patches".

Several researchers stress the importance of controlling Japanese stiltgrass along roadsides and trails in order to prevent its invasion into forest interiors [38,128,144]. Because Japanese stiltgrass seed production, cover, and rate of spread were significantly greater along roadsides than within oak-hickory and maple-beech-birch forest interiors of West Virginia, Huebner [94] also recommended making control of Japanese stiltgrass along roadsides a priority.

In all cases where invasive species are targeted for control, no matter what method is employed, the potential for other invasive species to fill their void must be considered [24]. Control of biotic invasions is most effective when it employs a long-term, ecosystem-wide strategy rather than a tactical approach focused on battling individual invaders [127].

Prevention: It is commonly argued that the most cost-efficient and effective method of managing invasive species is to prevent their establishment and spread by maintaining "healthy" natural communities [115,201,201] (for example, avoid road building in wildlands [221]) and monitoring several times each year [101]. Managing to maintain the integrity of the native plant community and mitigate the factors enhancing ecosystem invasibility is likely to be more effective than managing solely to control the invader [85]. Monitoring efforts are best concentrated on the most likely sites of invasion, particularly along potential pathways for Japanese stiltgrass invasion: waterways, roadsides, and adjacent old fields and woodlands. Periodically surveying to detect new invasions is recommended [224]. The Center for Invasive Plant Management provides an online guide to noxious weed prevention practices.

Weed prevention and control can be incorporated into many types of management plans, including those for logging and site preparation, grazing allotments, recreation management, research projects, road building and maintenance, and fire management [224]. Nord and others [152] suggested that Japanese stiltgrass invasion may be prevented if disturbed sites are kept free of Japanese stiltgrass seed and stolons (by, for example, cleaning logging or other equipment coming into disturbed sites), and that disturbed plant communities are likely to become less vulnerable to Japanese stiltgrass over time. The rate of Japanese stiltgrass population expansion decreased with time since disturbance on their Pennsylvanian oak-hickory-eastern white pine forest study sites [152]. See the Guide to noxious weed prevention practices [224] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions.

Swearingen [209] stresses that preventing the introduction of Japanese stiltgrass into uninfested areas, and early control of small infestations, should be a priority. Removing Japanese stiltgrass plants late in the growing season, before Japanese stiltgrass seed set but after seed set of most associated species, is recommended [72,233]. Once established, Japanese stiltgrass requires major, long-term eradication and restoration efforts. The Nature Conservancy [218] reports high potential for successful control and management of Japanese stiltgrass if it is detected and controlled in the early stages of invasion, but they report only moderate potential for Japanese stiltgrass control and large-scale wildland restoration in areas where Japanese stiltgrass is already well established. Tu [218] provides a contact list of managers who have used control measures (successful or not) on Japanese stiltgrass in Natural Areas.

Fire: For information on the use of prescribed fire to control this species, see Fire Management Considerations.

These methods of Japanese stiltgrass control are discussed below:

- Physical or mechanical control
- Biological control
- Cultural control
- Chemical control
- Integrated management
- Comparisons of different control methods

Physical or mechanical control: Hand-pulling, mowing, tilling, and flooding can help control Japanese stiltgrass. Hand-pulling controls small Japanese stiltgrass infestations [50]. Japanese stiltgrass is shallow-rooted and prefers moist soils; hence, it is usually easy to pull [45,209]. Hand-pulling is most effective in late summer (August-September) [40,209], when plants are tall and branched. Plants pulled before seed set can be left on site; plants with fruits should be bagged and removed. Hand-pulling disturbs the soil, and is likely to create microsites favorable for germination of soil-stored Japanese stiltgrass seed. Late summer pulling is advantageous because soil-stored seed does not have a long enough growing season to establish. Pulling in July or earlier is not recommended. Hand-pulling needs to be continued until the seed bank is exhausted, which may take several years [209,218]. Floodplains and other sites subject to continual replenishment of the seed bank require hand-pulling treatments indefinitely [218]. Japanese stiltgrass rapidly invaded newly contoured streambanks in a wetland undergoing restoration in North Carolina. Hand-pulling for 3 years reduced Japanese stiltgrass (59% vs. 80% cover on weeded and unweeded plots, respectively), but Japanese stiltgrass rapidly invaded the year after weeding stopped [45].

Mowing is recommended late in the growing season (August-September), when plants are flowering but before seed set. Because Japanese stiltgrass is an annual, late-season mowing curtails growth. Early-season mowing does not control Japanese stiltgrass because 1) seed-banked seeds can still establish and produce a new crop of seeds by the end of the growing season, and 2) plants cut in early summer respond with new growth and flower production soon after cutting [46,209,233].

Tilling also reduces Japanese stiltgrass [218]. Soil must be tilled late in the growing season to avoid establishment of soil-stored seed. Tilling may not be appropriate in Natural Areas and may damage desirable plants.

Flooding for 3 straight months, or intermittent inundation, may kill Japanese stiltgrass plants. It may not kill soil-stored seed [218].

Biological control: Japanese stiltgrass has few natural predators and pathogens in North America [35]. No biological control agents were available for Japanese stiltgrass control as of 2010 [209,218]. Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. Refer to these sources: [229,245] and the Weed control methods handbook [220] for background information and important considerations for developing and implementing biological control programs.

Cultural control: Little information was available on cultural control of Japanese stiltgrass as of 2010, but one study demonstrates how native-species planting after control treatment helped control Japanese stiltgrass. In a 3-year study in a native cane (*Arundinaria gigantea*) wetland in Palo Verde National Park, Costa Rica, Japanese stiltgrass became dominant on plots where nonnative Chinese privet had been removed and cane was not planted. However, cane became dominant on plots where it was planted after Chinese privet removal, and overall plant species diversity increased compared to plots where Chinese privet was removed but cane was not planted ($P \leq 0.05$ for all variables) [158].

Chemical control: Herbicides may provide initial control of a new invasion or a severe infestation, but used alone, they are rarely a complete or long-term solution to invasive species management [27]. Herbicides are most effective on large infestations when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations. Control with herbicides is temporary, as it does not change the conditions that allowed the invasion to occur (for example, [249]). See The Nature Conservancy's [220] Weed Control Methods Handbook for considerations on the use of herbicides in Natural Areas and detailed information on specific chemicals.

Extensive infestations of Japanese stiltgrass can be controlled with systemic herbicides [209]. Herbicides may be the only practical method to effectively control large infestations. Glyphosate may control Japanese stiltgrass [40], but since glyphosate is a nonselective herbicide, care must be taken to avoid drift onto desirable native species. The University of Tennessee reported good control of Japanese stiltgrass on their Ames Plantation, but they also reported that managing for a desirable plant community after Japanese stiltgrass was controlled was "difficult". The University found good control of Japanese stiltgrass with imazameth [218]. Because imazameth is selective for only a few plant species, it killed Japanese stiltgrass plants without killing associated native herbaceous species. Sethoxydim and fluazifop are grass-specific herbicides reported as giving some control for Japanese stiltgrass (Tu 2005 personal communication cited in [219]). See these references for further information on using herbicides to control Japanese stiltgrass: [59,79,105,132,181,181,218,247].

Integrated management: A combination of complementary control methods may be helpful for rapid and effective control of Japanese stiltgrass. Integrated management includes not only killing the target plant, but also establishing desirable species and discouraging nonnative, invasive species over the long term. Japanese stiltgrass control is rarely successful with only one method of control [163], but a combination of control methods may be effective. Unfortunately, few studies on using integrated management to control Japanese stiltgrass had been reported as of 2010.

The best way to prevent large Japanese stiltgrass infestations is to control small patches. Small patches of Japanese stiltgrass in Great Smoky Mountains National Park have been controlled through a combination of herbicides, mowing, and hand-pulling (Johnson 2001 cited in [50]). Prescribed fire may be used in combination with other control methods for Japanese stiltgrass. For example, burning can be used to help reduce litter and standing plant biomass prior to herbicide application for Japanese stiltgrass control [218].

Comparisons of different control methods: A comparison of 5 Japanese stiltgrass control methods in North Carolina suggest hand-pulling or a grass-specific herbicide are good choices for Japanese stiltgrass control. The control treatments were: 1) season-long hand-pulling, 2) fall mowing, 3) a single application of glyphosate in fall, 4) selective hand-pulling of only Japanese stiltgrass, or 5) fenoxaprop (a grass herbicide) application once or twice a year as needed. Fall treatments were done before Japanese stiltgrass was flowering. These treatments were conducted for 3 consecutive years on 2 sites. On the Duke Forest site, Japanese stiltgrass dominated the groundlayer of a loblolly pine plantation and was interfering with growth of loblolly pine regeneration. On the Schenck Memorial Forest site, Japanese stiltgrass and sweetgum seedlings dominated the ground layer of a white ash-American elm forest. After 3 years, all treatments reduced Japanese stiltgrass cover and presence in the seed bank compared to control plots. There were no significant differences in Japanese stiltgrass cover among treatments, but native plant recruitment and species richness were highest with selective hand-pulling of Japanese stiltgrass or fenoxaprop applications. Because it reduced recruitment of native woody species the most, glyphosate was considered the least effective for restoration purposes [103,106].

Some Japanese stiltgrass control treatments serve overall restoration objectives better than others. On 3 mixed-hardwood forest sites in southern Indiana, hand-pulling Japanese stiltgrass promoted cover of native grasses better than a postemergent herbicide (fluazifop) the first year after treatments, while either hand-pulling or postemergent herbicide best promoted forb cover. However, Japanese stiltgrass invaded hand-pulled areas the spring after treatment. Both pre- and postemergent herbicide prevented Japanese stiltgrass reinvasion the spring after treatment, although postemergent herbicide promoted higher overall native plant diversity. Seeding with native species did not increase native plant diversity over that of unseeded plots in posttreatment year 2 ($P<0.05$ for all variables) [65,66].

APPENDIX: FIRE REGIME TABLE

SPECIES: Microstegium vimineum

The following table provides fire regime information that may be relevant to Japanese stiltgrass habitats. Follow the links in the table to documents that provide more detailed information on these fire regimes. If you are interested in fire regimes of plant communities not listed below, see the Expanded Fire Regime Table.

Fire regime information on vegetation communities in which Japanese stiltgrass may occur. This information is taken from the LANDFIRE Rapid Assessment Vegetation Models [119], which were developed by local experts using available literature, local data, and/or expert opinion. This table summarizes fire regime characteristics for each plant community listed. The PDF file linked from each plant community name describes the model and synthesizes the knowledge available on vegetation composition, structure, and dynamics in that community. Cells are blank where information is not available in the Rapid Assessment Vegetation Model.

Northern Great Plains	Great Lakes	Northeast	South-central US
Southern Appalachians	Southeast		

Northern Great Plains

- Northern Plains Grassland
- Northern Plains Woodland

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northern Plains Grassland					
Northern tallgrass prairie	Replacement	90%	6.5	1	25
	Mixed	9%	63		
	Surface or low	2%	303		
Oak savanna	Replacement	7%	44		
	Mixed	17%	18		
	Surface or low	76%	4		
Northern Plains Woodland					
Oak woodland	Replacement	2%	450		
	Surface or low	98%	7.5		
Northern Great Plains wooded draws and ravines	Replacement	38%	45	30	100
	Mixed	18%	94		
	Surface or low	43%	40	10	
Great Plains floodplain	Replacement	100%	500		

Great Lakes

- Great Lakes Grassland
- Great Lakes Woodland

- Great Lakes Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Great Lakes Grassland					
Mosaic of bluestem prairie and oak-hickory	Replacement	79%	5	1	8
	Mixed	2%	260		
	Surface or low	20%	2		33
Great Lakes Woodland					
Great Lakes pine barrens	Replacement	8%	41	10	80
	Mixed	9%	36	10	80
	Surface or low	83%	4	1	20
Jack pine-open lands (frequent fire-return interval)	Replacement	83%	26	10	100
	Mixed	17%	125	10	
Northern oak savanna	Replacement	4%	110	50	500
	Mixed	9%	50	15	150
	Surface or low	87%	5	1	20
Great Lakes Forested					
Northern hardwood maple-beech-eastern hemlock	Replacement	60%	>1,000		
	Mixed	40%	>1,000		

Conifer lowland (embedded in fire-prone ecosystem)	Replacement	45%	120	90	220
	Mixed	55%	100		
Conifer lowland (embedded in fire-resistant ecosystem)	Replacement	36%	540	220	≥1,000
	Mixed	64%	300		
Great Lakes floodplain forest	Mixed	7%	833		
	Surface or low	93%	61		
	Surface or low		21%	300	
Minnesota spruce-fir (adjacent to Lake Superior and Drift and Lake Plain)	Replacement	79%	80		
Great Lakes pine forest, jack pine	Replacement	67%	50		
	Mixed	23%	143		
	Surface or low	10%	333		
Maple-basswood	Replacement	33%	≥1,000		
	Surface or low	67%	500		
Maple-basswood mesic hardwood forest (Great Lakes)	Replacement	100%	>1,000	≥1,000	>1,000
Maple-basswood-oak-aspen	Replacement	4%	769		
	Mixed	7%	476		
	Surface or low	89%	35		
Northern hardwood-eastern hemlock forest (Great Lakes)	Replacement	99%	>1,000		

Oak-hickory	Replacement	13%	66	1	
	Mixed	11%	77	5	
	Surface or low	76%	11	2	25
Pine-oak	Replacement	19%	357		
	Surface or low	81%	85		
Red pine-eastern white pine (frequent fire)	Replacement	38%	56		
	Mixed	36%	60		
	Surface or low	26%	84		
Red pine-eastern white pine (less frequent fire)	Replacement	30%	166		
	Mixed	47%	105		
	Surface or low	23%	220		
Great Lakes pine forest, eastern white pine-eastern hemlock (frequent fire)	Replacement	52%	260		
	Mixed	12%	>1,000		
	Surface or low	35%	385		
Eastern white pine-eastern hemlock	Replacement	54%	370		
	Mixed	12%	>1,000		
	Surface or low	34%	588		
Northeast					

- Northeast Grassland
- Northeast Woodland
- Northeast Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northeast Grassland					
Northern coastal marsh	Replacement	97%	7	2	50
	Mixed	3%	265	20	
Northeast Woodland					
Eastern woodland mosaic	Replacement	2%	200	100	300
	Mixed	9%	40	20	60
	Surface or low	89%	4	1	7
Pine barrens	Replacement	10%	78		
	Mixed	25%	32		
	Surface or low	65%	12		
Northeast Forested					
Northern hardwoods (Northeast)	Replacement	39%	≥1,000		
	Mixed	61%	650		
Eastern white pine-northern hardwood	Replacement	72%	475		
	Surface or low	28%	>1,000		

Northern hardwoods-eastern hemlock	Replacement	50%	≥1,000		
	Surface or low	50%	≥1,000		
Northern hardwoods-spruce	Replacement	100%	≥1,000	400	>1,000
Appalachian oak forest (dry-mesic)	Replacement	2%	625	500	≥1,000
	Mixed	6%	250	200	500
	Surface or low	92%	15	7	26
Beech-maple	Replacement	100%	>1,000		
Northeast spruce-fir forest	Replacement	100%	265	150	300
Southeastern red spruce-Fraser fir	Replacement	100%	500	300	≥1,000

South-central US

- South-central US Grassland
- South-central US Woodland
- South-central US Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
South-central US Grassland					
Bluestem-sacahuista	Replacement	70%	3.6	1	
	Mixed	30%	7.7	2	
Southern tallgrass prairie	Replacement	91%	5		
	Mixed	9%	50		

Oak savanna	Replacement	3%	100	5	110
	Mixed	5%	60	5	250
	Surface or low	93%	3	1	4
South-central US Woodland					
Oak-hickory savanna (East Texas)	Replacement	1%	227		
	Surface or low	99%	3.2		
Interior Highlands dry oak/bluestem woodland and glade	Replacement	16%	25	10	100
	Mixed	4%	100	10	
	Surface or low	80%	5	2	7
Oak woodland-shrubland-grassland mosaic	Replacement	11%	50		
	Mixed	56%	10		
	Surface or low	33%	17		
Interior Highlands oak-hickory-pine	Replacement	3%	150	100	300
	Surface or low	97%	4	2	10
Pine bluestem	Replacement	4%	100		
	Surface or low	96%	4		
South-central US Forested					
	Replacement	7%	250	50	300

Interior Highlands dry-mesic forest and woodland	Mixed	18%	90	20	150
	Surface or low	75%	22	5	35
Gulf Coastal Plain pine flatwoods	Replacement	2%	190		
	Mixed	3%	170		
	Surface or low	95%	5		
West Gulf Coastal plain pine (uplands and flatwoods)	Replacement	4%	100	50	200
	Mixed	4%	100	50	
	Surface or low	93%	4	4	10
West Gulf Coastal Plain pine-hardwood woodland or forest upland	Replacement	3%	100	20	200
	Mixed	3%	100	25	
	Surface or low	94%	3	3	5
Southern floodplain	Replacement	42%	140		
	Surface or low	58%	100		
Southern floodplain (rare fire)	Replacement	42%	≥1,000		
	Surface or low	58%	714		
Cross Timbers	Replacement	3%	170		
	Mixed	2%	250		
	Surface or low	94%	6		

Southern Appalachians

- Southern Appalachians Grassland
- Southern Appalachians Woodland
- Southern Appalachians Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southern Appalachians Grassland					
Bluestem-oak barrens	Replacement	46%	15		
	Mixed	10%	69		
	Surface or low	44%	16		
Eastern prairie-woodland mosaic	Replacement	50%	10		
	Mixed	1%	900		
	Surface or low	50%	10		
Southern Appalachians Woodland					
Appalachian shortleaf pine	Replacement	4%	125		
	Mixed	4%	155		
	Surface or low	92%	6		
Table Mountain-pitch pine	Replacement	5%	100		
	Mixed	3%	160		
	Surface or low	92%	5		

Oak-ash woodland	Replacement	23%	119		
	Mixed	28%	95		
	Surface or low	49%	55		
Southern Appalachians Forested					
Bottomland hardwood forest	Replacement	25%	435	200	≥1,000
	Mixed	24%	455	150	500
	Surface or low	51%	210	50	250
Mixed mesophytic hardwood	Replacement	11%	665		
	Mixed	10%	715		
	Surface or low	79%	90		
Appalachian oak-hickory-pine	Replacement	3%	180	30	500
	Mixed	8%	65	15	150
	Surface or low	89%	6	3	10
Eastern hemlock-eastern white pine-hardwood	Replacement	17%	≥1,000	500	>1,000
	Surface or low	83%	210	100	>1,000
Red pine-eastern white pine (frequent fire)	Replacement	38%	56		
	Mixed	36%	60		
	Surface or low	26%	84		

Eastern white pine-northern hardwood	Replacement	72%	475		
	Surface or low	28%	>1,000		
Oak (eastern dry-xeric)	Replacement	6%	128	50	100
	Mixed	16%	50	20	30
	Surface or low	78%	10	1	10
Appalachian Virginia pine	Replacement	20%	110	25	125
	Mixed	15%	145		
	Surface or low	64%	35	10	40
Appalachian oak forest (dry-mesic)	Replacement	6%	220		
	Mixed	15%	90		
	Surface or low	79%	17		

Southeast

- Southeast Grassland
- Southeast Woodland
- Southeast Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southeast Grassland					
Southeast Gulf Coastal Plain Blackland prairie and woodland	Replacement	22%	7		
	Mixed	78%	2.2		

Floodplain marsh	Replacement	100%	4	3	30
Palmetto prairie	Replacement	87%	2	1	4
	Mixed	4%	40		
	Surface or low	9%	20		
Southern tidal brackish to freshwater marsh	Replacement	100%	5		
Gulf Coast wet pine savanna	Replacement	2%	165	10	500
	Mixed	1%	500		
	Surface or low	98%	3	1	10
Southeast Woodland					
Longleaf pine/bluestem	Replacement	3%	130		
	Surface or low	97%	4	1	5
Longleaf pine (mesic uplands)	Replacement	3%	110	40	200
	Surface or low	97%	3	1	5
Longleaf pine-Sandhills prairie	Replacement	3%	130	25	500
	Surface or low	97%	4	1	10
Pond pine	Replacement	64%	7	5	500
	Mixed	25%	18	8	150
	Surface or low	10%	43	2	50

South Florida slash pine flatwoods	Replacement	6%	50	50	90
	Surface or low	94%	3	1	6
Atlantic wet pine savanna	Replacement	4%	100		
	Mixed	2%	175		
	Surface or low	94%	4		
Southeast Forested					
Sand pine scrub	Replacement	90%	45	10	100
	Mixed	10%	400	60	
Coastal Plain pine-oak-hickory	Replacement	4%	200		
	Mixed	7%	100		
	Surface or low	89%	8		
Atlantic white-cedar forest	Replacement	34%	200	25	350
	Mixed	8%	900	20	900
	Surface or low	59%	115	10	500
Maritime forest	Replacement	18%	40		500
	Mixed	2%	310	100	500
	Surface or low	80%	9	3	50
Mesic-dry flatwoods	Replacement	3%	65	5	150

	Surface or low	97%	2	1	8
Southern floodplain	Replacement	7%	900		
	Surface or low	93%	63		

*Fire Severities—
Replacement: Any fire that causes greater than 75% top removal of a vegetation-fuel type, resulting in general replacement of existing vegetation; may or may not cause a lethal effect on the plants.
Mixed: Any fire burning more than 5% of an area that does not qualify as a replacement, surface, or low-severity fire; includes mosaic and other fires that are intermediate in effects.
Surface or low: Any fire that causes less than 25% upper layer replacement and/or removal in a vegetation-fuel class but burns 5% or more of the area [82,118].

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SPECIES: Microstegium vimineum

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