SPECIES: Lythrum salicaria

INTRODUCTORY

SPECIES: Lythrum salicaria

DISTRIBUTION AND OCCURRENCE

SPECIES: Lythrum salicaria

GENERAL DISTRIBUTION:
Purple loosestrife occurs in all but 6 states of the continental United States [132]. It is found along the Atlantic coast from North Carolina to Maine [129] and is scattered but spreading in the western United States [82]. Purple loosestrife occurs most commonly in the United States in the Midwest and Northeast, corresponding closely with the geographic extent of the Wisconsin glaciation [82,125]. It is distributed across the southernmost tier of Canadian provinces from Newfoundland to British Columbia, with northern limits generally around 51° N [80]. The greatest concentrations in Canada are in southwestern Quebec, southern Ontario, southern Manitoba, and in British Columbia's lower Fraser Valley [47]. The Plants Database provides a map to purple loosestrife's distribution in the United States.

Considered native to Eurasia [125], purple loosestrife has a widespread circumpolar distribution throughout the northern hemisphere, except in extremely cold and arctic regions [113,129]. Although the precise origin of purple loosestrife colonization in North America is unknown, it was well established by the 1830s within coastal wetlands along the New England seaboard, having likely been introduced via ship ballast soil. Further introductions are thought to have occurred intentionally by early American horticulturalists. Initial spread of purple loosestrife into the interior of eastern North America occurred primarily via routes of maritime commerce, such as canals, rivers and the Great Lakes. Spread into the arid West appears to be closely related to development of irrigation systems within that region [129].

The following biogeographic classification systems are presented as a guide to demonstrate where purple loosestrife could potentially be found based on reported occurrence and on biological tolerance to factors likely to limit its distribution. For instance, because purple loosestrife does not tolerate salt water, classifications describing a variety of salt marsh habitats are excluded from these lists. Additionally, many of these classifications are named for predominantly upland habitats that nevertheless contain sometimes-substantial wetland areas where purple loosestrife could potentially occur. Precise distribution information is lacking because of gaps in the understanding of biological and ecological characteristics of non-native species and because introduced species may still be expanding their habitable range. Therefore these lists are speculative and may not be complete.

ECOSYSTEMS [41]:
FRES10 White-red-jack pine
FRES11 Spruce-fir
FRES12 Longleaf-slash pine
FRES13 Loblolly-shortleaf pine
FRES14 Oak-pine
FRES15 Oak-hickory
FRES16 Oak-gum-cypress
FRES17 Elm-ash-cottonwood
FRES18 Maple-beech-birch
FRES19 Aspen-birch
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine
FRES23 Fir-spruce
FRES24 Hemlock-Sitka spruce
FRES25 Larch
FRES26 Lodgepole pine
FRES27 Redwood
FRES28 Western hardwoods
FRES29 Sagebrush
FRES30 Desert shrub
FRES31 Shinnery
FRES32 Texas savanna
FRES33 Southwestern shrubsteppe
FRES34 Chaparral-mountain shrub
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES37 Mountain meadows
FRES38 Plains grasslands
FRES39 Prairie
FRES40 Desert grasslands
FRES41 Wet Grasslands
FRES42 Annual grasslands
FRES44 Alpine

STATES:

AL	AR	CA	CO	CT	DE	ID	IL	IN

IA	KS	KY	ME	MD	MA	MI	MN	MS
MO	MT	NE	NV	NH	NJ	NY	NC	ND
OH	OK	OR	PA	RI	SD	TN	TX	UT
VT	VA	WA	WV	WI	WY	DC		

AB	BC	MB	NB	NF
NS	ON	PE	PQ	SK

BLM PHYSIOGRAPHIC REGIONS [16]:
1 Northern Pacific Border
2 Cascade Mountains
3 Southern Pacific Border
4 Sierra Mountains
5 Columbia Plateau
6 Upper Basin and Range
7 Lower Basin and Range
8 Northern Rocky Mountains
9 Middle Rocky Mountains
10 Wyoming Basin
11 Southern Rocky Mountains
12 Colorado Plateau
13 Rocky Mountain Piedmont
14 Great Plains
15 Black Hills Uplift
16 Upper Missouri Basin and Broken Lands

KUCHLER [71] PLANT ASSOCIATIONS:
K001 Spruce-cedar-hemlock forest
K002 Cedar-hemlock-Douglas-fir forest
K003 Silver fir-Douglas-fir forest
K004 Fir-hemlock forest
K005 Mixed conifer forest
K006 Redwood forest
K007 Red fir forest
K008 Lodgepole pine-subalpine forest
K009 Pine-cypress forest
K010 Ponderosa shrub forest
K011 Western ponderosa forest
K012 Douglas-fir forest
K013 Cedar-hemlock-pine forest
K014 Grand fir-Douglas-fir forest
K015 Western spruce-fir forest
K016 Eastern ponderosa forest
K017 Black Hills pine forest

K018 Pine-Douglas-fir forest
K020 Spruce-fir-Douglas-fir forest
K021 Southwestern spruce-fir forest
K022 Great Basin pine forest
K023 Juniper-pinyon woodland
K024 Juniper steppe woodland
K025 Alder-ash forest
K026 Oregon oakwoods
K028 Mosaic of K002 and K026
K029 California mixed evergreen forest
K030 California oakwoods
K031 Oak-juniper woodland
K032 Transition between K031 and K037
K033 Chaparral
K034 Montane chaparral
K035 Coastal sagebrush
K036 Mosaic of K030 and K035
K037 Mountain-mahogany-oak scrub
K038 Great Basin sagebrush
K039 Blackbrush
K040 Saltbush-greasewood
K041 Creosote bush
K042 Creosote bush-bur sage
K043 Paloverde-cactus shrub
K045 Ceniza shrub
K046 Desert: vegetation largely lacking
K047 Fescue-oatgrass
K048 California steppe
K049 Tule marshes
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K052 Alpine meadows and barren
K054 Grama-tobosa prairie
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe
K057 Galleta-threeawn shrubsteppe
K059 Trans-Pecos shrub savanna
K060 Mesquite savanna
K061 Mesquite-acacia savanna
K062 Mesquite-live oak savanna
K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass
K065 Grama-buffalo grass
K066 Wheatgrass-needlegrass
K067 Wheatgrass-bluestem-needlegrass
K068 Wheatgrass-grama-buffalo grass
K069 Bluestem-grama prairie
K070 Sandsage-bluestem prairie
K071 Shinnery
K072 Sea oats prairie
K073 Northern cordgrass prairie

K074 Bluestem prairie
K075 Nebraska Sandhills prairie
K076 Blackland prairie
K077 Bluestem-sacahuista prairie
K078 Southern cordgrass prairie
K081 Oak savanna
K082 Mosaic of K074 and K100
K083 Cedar glades
K084 Cross Timbers
K085 Mesquite-buffalo grass
K086 Juniper-oak savanna
K087 Mesquite-oak savanna
K088 Fayette prairie
K089 Black Belt
K090 Live oak-sea oats
K093 Great Lakes spruce-fir forest
K094 Conifer bog
K095 Great Lakes pine forest
K096 Northeastern spruce-fir forest
K097 Southeastern spruce-fir forest
K098 Northern floodplain forest
K099 Maple-basswood forest
K100 Oak-hickory forest
K101 Elm-ash forest
K102 Beech-maple forest
K103 Mixed mesophytic forest
K104 Appalachian oak forest
K106 Northern hardwoods
K107 Northern hardwoods-fir forest
K108 Northern hardwoods-spruce forest
K109 Transition between K104 and K106
K110 Northeastern oak-pine forest
K111 Oak-hickory-pine
K112 Southern mixed forest
K113 Southern floodplain forest
K114 Pocosin

SAF COVER TYPES [36]:
1 Jack pine
5 Balsam fir
12 Black spruce
13 Black spruce-tamarack
14 Northern pin oak
15 Red pine
16 Aspen
17 Pin cherry
18 Paper birch
19 Gray birch-red maple
20 White pine-northern red oak-red maple
21 Eastern white pine
22 White pine-hemlock
23 Eastern hemlock

24 Hemlock-yellow birch
25 Sugar maple-beech-yellow birch
26 Sugar maple-basswood
27 Sugar maple
28 Black cherry-maple
30 Red spruce-yellow birch
31 Red spruce-sugar maple-beech
32 Red spruce
33 Red spruce-balsam fir
34 Red spruce-Fraser fir
35 Paper birch-red spruce-balsam fir
37 Northern white-cedar
38 Tamarack
39 Black ash-American elm-red maple
40 Post oak-blackjack oak
42 Bur oak
43 Bear oak
44 Chestnut oak
45 Pitch pine
46 Eastern redcedar
50 Black locust
51 White pine-chestnut oak
52 White oak-black oak-northern red oak
53 White oak
55 Northern red oak
57 Yellow-poplar
58 Yellow-poplar-eastern hemlock
59 Yellow-poplar-white oak-northern red oak
60 Beech-sugar maple
61 River birch-sycamore
62 Silver maple-American elm
63 Cottonwood
64 Sassafras-persimmon
65 Pin oak-sweetgum
66 Ashe juniper-redberry (Pinchot) juniper
67 Mohrs (shin) oak
68 Mesquite
69 Sand pine
70 Longleaf pine
71 Longleaf pine-scrub oak
72 Southern scrub oak
73 Southern redcedar
74 Cabbage palmetto
75 Shortleaf pine
76 Shortleaf pine-oak
78 Virginia pine-oak
79 Virginia pine
80 Loblolly pine-shortleaf pine
81 Loblolly pine
82 Loblolly pine-hardwood
83 Longleaf pine-slash pine

84 Slash pine
85 Slash pine-hardwood
87 Sweetgum-yellow-poplar
88 Willow oak-water oak-diamondleaf (laurel) oak
89 Live oak
91 Swamp chestnut oak-cherrybark oak
92 Sweetgum-willow oak
93 Sugarberry-American elm-green ash
94 Sycamore-sweetgum-American elm
95 Black willow
96 Overcup oak-water hickory
97 Atlantic white-cedar
98 Pond pine
100 Pondcypress
101 Baldcypress
102 Baldcypress-tupelo
103 Water tupelo-swamp tupelo
104 Sweetbay-swamp tupelo-redbay
107 White spruce
108 Red maple
109 Hawthorn
110 Black oak
201 White spruce
202 White spruce-paper birch
203 Balsam poplar
204 Black spruce
205 Mountain hemlock
206 Engelmann spruce-subalpine fir
207 Red fir
208 Whitebark pine
209 Bristlecone pine
210 Interior Douglas-fir
211 White fir
212 Western larch
213 Grand fir
215 Western white pine
216 Blue spruce
217 Aspen
218 Lodgepole pine
219 Limber pine
220 Rocky Mountain juniper
221 Red alder
222 Black cottonwood-willow
223 Sitka spruce
224 Western hemlock
225 Western hemlock-Sitka spruce
226 Coastal true fir-hemlock
227 Western redcedar-western hemlock
228 Western redcedar
229 Pacific Douglas-fir
230 Douglas-fir-western hemlock

231 Port-Orford-cedar
232 Redwood
233 Oregon white oak
234 Douglas-fir-tanoak-Pacific madrone
235 Cottonwood-willow
236 Bur oak
237 Interior ponderosa pine
238 Western juniper
239 Pinyon-juniper
242 Mesquite
243 Sierra Nevada mixed conifer
244 Pacific ponderosa pine-Douglas-fir
245 Pacific ponderosa pine
246 California black oak
247 Jeffrey pine
248 Knobcone pine
249 Canyon live oak
250 Blue oak-foothills pine
251 White spruce-aspen
252 Paper birch
253 Black spruce-white spruce
254 Black spruce-paper birch
255 California coast live oak
256 California mixed subalpine

SRM (RANGELAND) COVER TYPES [115]:
101 Bluebunch wheatgrass
102 Idaho fescue
103 Green fescue
104 Antelope bitterbrush-bluebunch wheatgrass
105 Antelope bitterbrush-Idaho fescue
106 Bluegrass scabland
107 Western juniper/big sagebrush/bluebunch wheatgrass
108 Alpine Idaho fescue
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
201 Blue oak woodland
202 Coast live oak woodland
203 Riparian woodland
204 North coastal shrub
205 Coastal sage shrub
206 Chamise chaparral
207 Scrub oak mixed chaparral
208 Ceanothus mixed chaparral
209 Montane shrubland
210 Bitterbrush
211 Creosote bush scrub
212 Blackbush
213 Alpine grassland
214 Coastal prairie
215 Valley grassland
216 Montane meadows

217 Wetlands
301 Bluebunch wheatgrass-blue grama
302 Bluebunch wheatgrass-Sandberg bluegrass
303 Bluebunch wheatgrass-western wheatgrass
304 Idaho fescue-bluebunch wheatgrass
305 Idaho fescue-Richardson needlegrass
306 Idaho fescue-slender wheatgrass
307 Idaho fescue-threadleaf sedge
308 Idaho fescue-tufted hairgrass
309 Idaho fescue-western wheatgrass
310 Needle-and-thread-blue grama
311 Rough fescue-bluebunch wheatgrass
312 Rough fescue-Idaho fescue
313 Tufted hairgrass-sedge
314 Big sagebrush-bluebunch wheatgrass
315 Big sagebrush-Idaho fescue
316 Big sagebrush-rough fescue
317 Bitterbrush-bluebunch wheatgrass
318 Bitterbrush-Idaho fescue
319 Bitterbrush-rough fescue
320 Black sagebrush-bluebunch wheatgrass
321 Black sagebrush-Idaho fescue
322 Curlleaf mountain-mahogany-bluebunch wheatgrass
323 Shrubby cinquefoil-rough fescue
324 Threetip sagebrush-Idaho fescue
401 Basin big sagebrush
402 Mountain big sagebrush
403 Wyoming big sagebrush
404 Threetip sagebrush
405 Black sagebrush
406 Low sagebrush
407 Stiff sagebrush
408 Other sagebrush types
409 Tall forb
410 Alpine rangeland
411 Aspen woodland
412 Juniper-pinyon woodland
413 Gambel oak
414 Salt desert shrub
415 Curlleaf mountain-mahogany
416 True mountain-mahogany
417 Littleleaf mountain-mahogany
418 Bigtooth maple
419 Bittercherry
420 Snowbrush
421 Chokecherry-serviceberry-rose
422 Riparian
501 Saltbush-greasewood
505 Grama-tobosa shrub
506 Creosotebush-bursage
507 Palo verde-cactus

508 Creosotebush-tarbush
601 Bluestem prairie
602 Bluestem-prairie sandreed
603 Prairie sandreed-needlegrass
604 Bluestem-grama prairie
605 Sandsage prairie
606 Wheatgrass-bluestem-needlegrass
607 Wheatgrass-needlegrass
608 Wheatgrass-grama-needlegrass
609 Wheatgrass-grama
610 Wheatgrass
611 Blue grama-buffalo grass
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass
615 Wheatgrass-saltgrass-grama
701 Alkali sacaton-tobosagrass
702 Black grama-alkali sacaton
703 Black grama-sideoats grama
704 Blue grama-western wheatgrass
705 Blue grama-galleta
706 Blue grama-sideoats grama
707 Blue grama-sideoats grama-black grama
708 Bluestem-dropseed
709 Bluestem-grama
710 Bluestem prairie
711 Bluestem-sacahuista prairie
712 Galleta-alkali sacaton
713 Grama-muhly-threeawn
714 Grama-bluestem
715 Grama-buffalo grass
716 Grama-feathergrass
717 Little bluestem-Indiangrass-Texas wintergrass
718 Mesquite-grama
719 Mesquite-liveoak-seacoast bluestem
720 Sand bluestem-little bluestem (dunes)
721 Sand bluestem-little bluestem (plains)
722 Sand sagebrush-mixed prairie
723 Sea oats
724 Sideoats grama-New Mexico feathergrass-winterfat
725 Vine mesquite-alkali sacaton
726 Cordgrass
727 Mesquite-buffalo grass
728 Mesquite-granjeno-acacia
729 Mesquite
730 Sand shinnery oak
731 Cross timbers-Oklahoma
732 Cross timbers-Texas (little bluestem-post oak)
733 Juniper-oak
734 Mesquite-oak
735 Sideoats grama-sumac-juniper

801 Savanna
802 Missouri prairie
803 Missouri glades
804 Tall fescue
805 Riparian
807 Gulf Coast fresh marsh

HABITAT TYPES AND PLANT COMMUNITIES:
Purple loosestrife is found across a variety of freshwater wetland habitats in North America, and consequently is associated with a variety of plant taxa, functional guilds and communities. Habitats where it is likely to be found include: freshwater marshes [27,94,102,105,127,129], streambanks or lakeshores [130], floodplains [81,102,129], seasonally-wet meadows/wet prairies [8,10,129], bogs [127], vernal ponds [59], openings in forested swamps [64], intermittent streams [105], shallow impoundments, and ditches and canals [102,105]. Purple loosestrife is listed by the U.S. Fish and Wildlife Service Office of Biological Services as a typical broadleaf plant of Palustrine Persistent Emergent Wetlands [30].

In a host-specificity test of potential biological control agents for purple loosestrife, Blossey and Schroeder [21] included 13 plant species said to "occur in the same habitat" as purple loosestrife and were "of wildlife importance." Although these species are not necessarily distributed homogeneously or systematically across the North American landscape, they likely represent a reasonable sample of typical plant associates. These species were common cattail (*Typha latifolia*), broadfruit bur-reed (*Sparganium eurycarpum*), broadleaf arrowhead (*Sagittaria latifolia*), annual wildrice (*Zizania aquatica*), Olney threesquare (*Scirpus americanus*), hardstem bulrush (*Scirpus acutus*), longhair sedge (*Carex comosa*), sandbar willow (*Salix exigua*), curly dock (*Rumex crispus*), longroot smartweed (*Polygonum amphibium*), lambsquarters (*Chenopodium album*), cursed buttercup (*Ranunculus sceleratus*) and St. Anthony's turnip (*Ranunculus bulbosus*).

Classifications describing plant communities in which purple loosestrife is a dominant species are:

New York [105]

Washington [59]

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Lythrum salicaria

- GENERAL BOTANICAL CHARACTERISTICS
- RAUNKIAER LIFE FORM
- REGENERATION PROCESSES
- SITE CHARACTERISTICS
- SUCCESSIONAL STATUS
- SEASONAL DEVELOPMENT

GENERAL BOTANICAL CHARACTERISTICS:
Purple loosestrife is a non-native, perennial wetland herb [14,129]. Stems are erect, 1 to 8 feet (0.3-2.4 m) tall, becoming woody with age and persisting through winter and up to 2 years [9,14,74,118]. Mature, long-established plants are often 10 feet (3 m) tall and 5 feet (1.5 m) wide [129]. Plants may become increasingly bush-like by producing greater numbers of basal stems from the same rootstock each year [14,80,118,129]. Plants begin producing multiple stems from a single rootstock as early as the 2nd growing season [102]. Anderson [1] recorded single genets with over 130 stems produced from a single rootstock

during a single season. He also estimated ages for individual plants up to 22 years. Observations have been recorded of particular rootstocks failing to generate shoots during a given year, but producing aboveground growth during each prior and subsequent season [129].

Leaves are 2 to 6 inches (5-14 cm) long and attached close to the stem [14]. Flower spikes vary in length from > 40 inches (1 m) to only a few inches, and only 2 to 3 inches (5.1-7.6 cm) of the spike typically display open flowers at any given time [9,74]. Fruits are capsules 2-3 mm in length [57]. Seeds measure approximately 400 x 200 microns, and weigh approximately 1.8 x 10^{-6} ounces (50 µg) per seed, which is comparatively quite small among North American temperate wetland plants [116,129].

Seedlings quickly develop a thick, hardened taproot [113]. Mature plants subjected to persistent flooding respond by forming aerenchymous (containing large intercellular air spaces) tissue, permitting oxygen flow to submerged roots [118].

The preceding description provides characteristics of purple loosestrife that may be relevant to fire ecology and is not meant to be used for identification. Keys for identifying purple loosestrife are available in various floras (e.g. [58,72]). Photos and descriptions of purple loosestrife are also available online from The Nature Conservancy's Wildlands Invasive Species Team and Minnesota Sea Grant. Check with the native plant society or cooperative extension service in your state for more information.

RAUNKIAER [100] LIFE FORM:
Hemicryptophyte
Helophyte

REGENERATION PROCESSES:
Breeding system: Purple loosestrife is a tristylous species (3 different style lengths), usually in a 1:1:1 ratio, indicating sexual reproduction is probably its most important means of regeneration [9]. It is primarily an outcrosser, as self-pollination in purple loosestrife is rare, and has been shown to reduce seed production [113].

Pollination: Purple loosestrife is insect pollinated. Most reports indicate honeybees are the main pollinators [44,74]. Others include bumblebees [73,74], leaf-cutter bees and carpenter bees [73], as well as a variety of butterflies [73,74]. Hummingbirds have been observed taking nectar from purple loosestrife in British Columbia [98], although pollination by hummingbirds is undocumented.

Seed production:
Purple loosestrife produces an immense number of seeds. Estimates of seed production rates range from just over 100,000 seeds per plant for young plants with single stems [113], to over 2.5 million seeds per plant for established plants with an average of 30 stems per plant [129]. Although perennial, purple loosestrife is capable of producing viable seed during its 1st growing season [116]. Seed output is largely a function of plant age, size, and vigor [129]. Shoots growing in relatively dense stands tend to produce fewer and smaller inflorescences than those growing in more open areas [102].

Seed dispersal: Because seeds are small and light they are thought to be dispersed, at least in part, by wind [54,113]. However, Thompson and others [129] report observations that seedling densities decline sharply within a 33 foot (10 m) perimeter of the parent plant and seedlings are often distributed downslope from the parent plant rather than downwind, suggesting a limited role for wind dispersal. Dispersal via moving water is also likely [54,118,119]. Seeds and cotyledon stage seedlings are reportedly buoyant [9], although there are reports that purple loosestrife seeds don't float [119]. Floating seeds may disperse to suitable sites for establishment. Seeds that sink may germinate while submerged, then rise to the surface and drift to suitable sites for establishment [129]. Seeds may be transported in fur of mammals, plumage of waterfowl, mud attached to footgear, vehicle treads or cooling systems of outboard motors [54,128,129]. Thompson and others [129] also suggest birds may deposit ingested seeds in areas where wind or gravity-mediated dispersal seems unlikely.

Seed banking:
Given its high seed output and ability to produce seed in its 1st growing season, purple loosestrife can establish substantial soil seed banks. Seeds may remain viable for at least 2 to 3 years [102,113], although the long-term viability of seeds stored in the soil seed bank remains under investigation [139]. Seeds may remain viable even when subjected to saturating conditions. Viability of seeds that were stored underwater was tested at 4-month intervals under ideal germination conditions. Germination declined from an initial rate of 99% to 93% after 1 year and 80% after 2 years [102].

Purple loosestrife has the potential to dominate the soil seed bank where it becomes well established. Soil samples taken from within purple loosestrife stands in emergent wetlands in southeastern Minnesota contained an average of 37,963 purple loosestrife seeds per ft^2 (410,000 $/m^2$) in the top 2 in (5 cm) of soil. Seeds were distributed within this entire profile and seed density increased with proximity to the soil surface. Under greenhouse conditions chosen to promote germination, and using soil samples from the above source spread 0.4 in (1 cm) deep, recruitment failed to exhaust the seed bank [138,140]. From the same experiment, purple loosestrife seedlings were found in 91% of untreated (no herbicide) 6.6 x 6.6 feet (2 x 2 m) quadrats, the most frequently encountered species in the soil seed bank [140].

Germination:
Germination is greatest in unshaded, wet soils, with temperatures >68 degrees Fahrenheit (20º C) [20]. Shamsi and Whitehead [113] demonstrated germination is constrained at low temperatures between about 50 to 59 degrees Fahrenheit (10°-15° C), and no germination occurred below 57 degrees Fahrenheit (14° C). Experimental evidence indicates seed dormancy may be enforced by burial, with germination response decreasing linearly ($p = 0.001$, $r^2 = 0.89$) from 90% at the soil surface to 0% at 0.8 in (2 cm), even under conditions known to promote germination in wetland plants [138]. Any disturbance that redistributes seeds to within the upper 0.8 inch (2 cm) of soil is likely to promote germination. Although light exposure is a prerequisite for germination, length of exposure does not appear important [111]. Purple loosestrife seeds are capable of germinating underwater [65].

Seedling establishment/growth:
Favorable recruitment conditions are largely a function of disturbance that creates areas where little to no vegetation is present [99]. Estimates of maximum initial seedling density vary greatly, from 926 to 1,852 $foot^{-2}$ (10,000-20,000 m^{-2}) on bare open mudflats [102] to 2.8 to 4.6 $foot^{-2}$ (30-50 m^{-2}) in vegetated semiflooded wetlands. In areas where large numbers of seeds are present in the seed bank, small changes in area favorable for establishment can yield large fluctuations in recruitment [1].

In order to begin successful establishment, floating seeds or propagules must settle on moist soil [129]. Purple loosestrife can establish in soil beneath standing water [65].

Growth is limited by cold temperature and is considerably slowed at around 46 to 50 degrees Fahrenheit (8-10º C) [141]. Light availability can also limit growth and development. Under diminishing light intensities, vegetative growth is slowed, the numbers of flowers, fruits, and seeds per fruit are fewer, and the average dry weight of fruits declines, but there is no change in average dry weight of individual seeds [111]. Growth is also affected by day length. Shamsi and Whitehead [111] found leaf area and plant dry weight were significantly ($P<0.05$) reduced when plants were subjected to a 9-hour photoperiod compared with a 16-hour photoperiod. Plants in the 9-hour treatment grew in a comparatively flattened, semi-prostrate condition.

Asexual regeneration:
The rootstock is the main organ of perennation, and unaided wide vegetative spread is unlikely. New shoots arise from buds at the top of the rootstock [113]. Root crowns expand annually to accommodate increasing numbers of shoots, but may reach maximum growth at around 20 inches (0.5 m) in diameter [129].

Purple loosestrife can consistently resprout in response to aboveground damage, often fairly rapidly. A greenhouse experiment showed 91% of clipped seedlings resprouted within 42 days [40]. Live stems that are dislodged and buried can give rise to new shoots via adventitious buds [23,129].

SITE CHARACTERISTICS:
Throughout its global distribution purple loosestrife is strongly linked with temperate climate and moist or saturated soils [129]. Unshaded, newly-exposed, moist soil appears most favorable for seedling establishment. Riverine habitats subjected to periodic but infrequent scouring, or lacustrine habitats subject to periodic water level reduction such as drought-exposed lakeshore or seasonal impoundment drawdown are good examples of habitats at risk of invasion. Once purple loosestrife seedlings become established, adults are quite flood tolerant [118]. Moisture is the most critical factor for growth and reproduction, but well-established plants can persist at dry sites for many years [21]. Keddy and Ellis [65] examined purple loosestrife seedling recruitment along a water level gradient, simulating conditions ranging from water levels 2 inches (5 cm) below the soil surface to standing water up to 4 inches (10 cm) above the soil surface. They found there was no significant ($p = 0.44$) effect of water depth on germination and early establishment of seedlings, indicating a broad tolerance for water level in the recruitment phase of purple loosestrife life history. Stream corridors with steep elevational gradients may be less susceptible to colonization by purple loosestrife due to gravitational constraints on seed dispersal [128].

Northern limits of purple loosestrife distribution may be strongly influenced by low growing season temperature. Under controlled conditions, growth was severely restricted at 46.4 degrees Fahrenheit (8 °C) compared with more "characteristic" growth at 64.4 degrees Fahrenheit (18°C) [112].

Purple loosestrife is found on both calcareous and acidic soils [112,113,129] and tolerates low-nutrient soils [113,117,141]. Typically found in open areas, purple loosestrife will tolerate some shade, but growth, reproduction and survival may be substantially reduced under shaded conditions [110,118].

Several characteristics of wetland or riparian habitats have been identified that may be predictive of invasibility by purple loosestrife. Assuming dispersal is largely via floating propagules, isolated wetland basins may be less susceptible to purple loosestrife colonization than areas with interconnected waterways. Additionally, narrow streams with steep gradients are probably less susceptible, because they are frequently scoured and contain fewer areas of slack water, while slower, broader flows are more likely to contain habitat suitable for colonization. Riparian areas that are mostly shaded are also less susceptible because purple loosestrife seedlings require relatively high light levels. Finally, the presence of one or more commonly associated taxa, such as cattails (*Typha* spp.), reed canarygrass (*Phalaris arundinacea*), sedges (*Carex*) spp., and rushes (*Juncus* spp.) may indicate a habitat that is highly susceptible to invasion by purple loosestrife [129].

SUCCESSIONAL STATUS:
The ways and extent to which purple loosestrife affects succession in wetland plant communities are not altogether clear. It is evident that purple loosestrife requires open, moist, bare substrate for establishment (see Site Characteristics and Regeneration Processes). It is generally agreed that purple loosestrife is a pioneer or gap-colonizing species that quickly responds to site disturbance by recruiting often-substantial numbers of new genets from a pre-existing seed bank [1,31,110].

Purple loosestrife displays many characteristics typical of pioneer species, such as rapid maturity, high seed production, tolerance of nutrient-poor environments, and high germination success. Yet North American populations, once established, also are potentially long-lived (22+ years), capable of growing to a relatively large size, and have shown the propensity for near-continuous, low-level recruitment in the absence of large-scale disturbance [1,129]. While evidence is somewhat limited, it is speculated natural mortality rates in adult plants are quite low [1].

Purple loosestrife, once established, can persist within a site for relatively long periods, even in the absence of frequent disturbance. After examining purple loosestrife population structure within several different communities in eastern Massachusetts, Anderson [1] concluded low levels of nearly-continuous recruitment are likely to occur in areas where mature plants (and the inevitable prodigious purple loosestrife seed bank) are present. Additionally, this trend is punctuated by occasional disturbances that provide conditions suitable for short-lived recruitment episodes in which relatively large cohorts of new plants are established.

But there is some question regarding the view that purple loosestrife inevitably dominates invaded sites in virtual monotypic stands. Anderson [2] points out that in a widely cited review by Thompson and others [129], estimates of the proportion of stand biomass attributed to purple loosestrife, which ostensibly increased over time following establishment, may instead have been attributable to increases in the number of stems per genet rather than greater numbers of individual plants. The number of annually produced stems per single genetically distinct plant has been shown to be a good predictor of the age of that individual [1]. Anderson [2] also notes observations described in Thompson and others [129] were strictly visual assessments, and since no hard data was collected, there is no way to definitively ascertain what, if any, changes in biomass distribution among species may have occurred.

In its native range, European populations of purple loosestrife may also form large monospecific stands following pregrowing season disturbance, but are prone to invasion by other species soon after stand establishment [110,113]. Whitehead [141] described the gradual yielding of monospecific stands of purple loosestrife to mixed species communities in England as being due to slow growth of purple loosestrife during periods of cool spring temperatures compared with competitors possessing low-temperature growth capabilities such as cattails or reeds (*Phragmites* spp.) It is likely that an aggregate of factors act to limit purple loosestrife site dominance in its native habitats [118].

Thompson and others [129] have reviewed several historical accounts of purple loosestrife stands, both in its native Europe and elsewhere. They determined that while purple loosestrife seldom maintains strong community dominance in native (European) habitats, it commonly forms dense, long-lasting, virtually monospecific stands in areas where it is not native, especially temperate North America. They considered 3 factors that could possibly account for this phenomenon: 1) the absence of many key insect predators that effectively reduce competitiveness of European purple loosestrife plants, 2) predominance of the muskrat in its native North American habitat and the impact of its selective foraging behavior on cattails (see Importance to Livestock and Wildlife or Impacts and Control), and 3) the possibility that North American purple loosestrife may have evolved adaptive traits which make it more vigorous and competitive than its European relatives.

Many factors are likely to affect the ability of purple loosestrife to form and maintain extensive monodominant stands in North American wetlands. Characteristics particular to certain classes of habitat may lead to monodominance. Auclair and others [8] have noted some trends in 2 distinct plant communities of Huntington Marsh, located along the St. Lawrence River near the junction of the Quebec, Ontario and New York borders. In the emergent aquatic community, the dominant emergent taxa tended to exclude each other, resulting in a mosaic of nearly monospecific communities. In particular, river bulrush (*Schoenoplectus fluviatilis*), common reed (*Phragmites australis*) and narrow-leaved cattail (*Typha angustifolia*) displayed this phenomenon. In contrast, sedge meadow communities were much more diverse and lacked the dominance and segregation of species. Instead they demonstrated subtle gradients in composition that were generally difficult to discern.

The nature of particular disturbance events may also impact initial floristics and subsequent successional trajectories. For instance, the relative competitiveness of purple loosestrife seedlings following disturbance may depend upon when initiation of the new seedling community occurs within the growing season. Because purple loosestrife growth rates are closely linked to day length [111], early summer establishment of a seedling cohort or community, compared with late summer establishment, is more likely to result in a monospecific stand of purple loosestrife because purple loosestrife seedlings will be more competitive [102].

More research is needed to help elucidate the means and extent to which purple loosestrife alters successional trajectories and community dynamics. Long-term studies that examine preinvasion vs. postinvasion data would be particularly helpful.

SEASONAL DEVELOPMENT:
Flowering typically occurs 8 to10 weeks following germination [113]. Onset of rapid growth and eventual flowering is strongly influenced by photoperiod length. Purple loosestrife plants grown under controlled conditions were examined for effects of day length on growth and development. It was determined a critical photoperiod of 13 hours is required to enable formation of "highly competitive morphogenetic entities". When subjected to shorter daylength, plants had substantially reduced vegetative growth and little to no flowering. [111]. Most reports indicate flowering commences sometime in June and ceases in September [20,49,102,129]. Both mature plants and seedlings whose growth rates were tracked throughout the growing season in central New York reached at least 90% of their final height by August 3 [102]. Senescence proceeds with the onset of fall frost, marked by the turning red, fading and abscission of leaves. Dead but rigid stems remain standing through winter and spring. Seed capsules also remain attached to flower stalks through winter [128].

FIRE ECOLOGY

SPECIES: Lythrum salicaria

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:
Fire adaptations:
Purple loosestrife is an herbaceous perennial, with growing points that overwinter on the root crown about 0.8 inches (2 cm) below the soil surface (see Botanical and Ecological Characteristics). Consequently, it is likely to survive the heat of most surface fires. In addition, postsenescent purple loosestrife stems remain standing through winter. Because a substantial amount of fuel remains standing in monodominant stands at any given time, and because it occurs on mostly wet soils, very little accumulation of fine fuels occurs on the soil surface. As a result, fire in purple loosestrife is unlikely to provide enough heat or burn for a long enough duration to cause substantial damage to belowground plant organs [129].

Fire regimes: Because purple loosestrife is distributed across many habitats in North America (see Distribution and Occurrence), fire regimes associated with the species vary. Recurrence and behavior of fire in areas where purple loosestrife occurs is likely to be closely tied to particular local fire regimes, and cannot be easily summarized over broad spatial scales. Given purple loosestrife's moisture requirements, it is unlikely to occur in areas experiencing frequently recurring fire. Similar to many areas that experience fire infrequently, occurrence of fire in areas where purple loosestrife is found is likely to driven by drought. However, information describing interactions between purple loosestrife and fire are lacking, and information linking purple loosestrife to specific North American fire regimes is nonexistent.

Given the dearth of information on fire and purple loosestrife and our relatively poor understanding of how purple loosestrife generally affects plant community dynamics where it occurs, any description of interactions between particular fire regimes and purple loosestrife is speculative. Where purple loosestrife displaces native vegetation dependent upon recurring fire for maintenance of a seral stage, persistent stands of invasive purple loosestrife may alter fire regimes if purple loosestrife burns less frequently or less readily than the native vegetation it displaces. For example, sedge meadow communities along the St. Lawrence River in southern Quebec where purple loosestrife is sometimes found, are historically maintained by dormant season fire recurring every 1 to 3 years. If invading purple loosestrife reduces fire frequency or severity at these sites, these communities are likely to succeed to woody species such as willow (*Salix* spp.) or maple (*Acer* spp.) [8].

The following table lists fire return intervals for communities or ecosystems throughout North America where purple loosestrife may occur. This list is not intended as a description of purple loosestrife distribution, but rather as a guide to fire regimes in areas where purple loosestrife could potentially be found. (For more specific distributional information see Distribution and Occurrence). While this list mainly describes upland habitats, purple loosestrife is generally associated with wetland or riparian habitats within these communities or ecosystems. As such, this list is meant as a guideline to illustrate historic fire regimes and is not to be interpreted as a strict description of fire regimes for purple loosestrife.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
silver fir-Douglas-fir	*Abies amabilis-Pseudotsuga menziesii* var. *menziesii*	> 200
grand fir	*Abies grandis*	35-200 [5]
maple-beech-birch	*Acer-Fagus-Betula*	> 1000
silver maple-American elm	*Acer saccharinum-Ulmus americana*	< 35 to 200
sugar maple	*Acer saccharum*	> 1000
sugar maple-basswood	*Acer saccharum-Tilia americana*	> 1000 [135]
California chaparral	*Adenostoma* and/or *Arctostaphylos* spp.	< 35 to < 100 [95]
bluestem prairie	*Andropogon gerardii* var. *gerardii-Schizachyrium scoparium*	< 10 [70,95]
Nebraska sandhills prairie	*Andropogon gerardii* var. *paucipilus-Schizachyrium scoparium*	< 10
bluestem-Sacahuista prairie	*Andropogon littoralis-Spartina spartinae*	< 10
sagebrush steppe	*Artemisia tridentata/Pseudoroegneria spicata*	20-70
basin big sagebrush	*Artemisia tridentata* var. *tridentata*	12-43 [108]
mountain big sagebrush	*Artemisia tridentata* var. *vaseyana*	15-40 [6,25,86]
Wyoming big sagebrush	*Artemisia tridentata* var. *wyomingensis*	10-70 (40**) [133,143]
coastal sagebrush	*Artemisia californica*	< 35 to < 100
saltbush-greasewood	*Atriplex confertifolia-Sarcobatus vermiculatus*	< 35 to < 100
desert grasslands	*Bouteloua eriopoda* and/or *Pleuraphis mutica*	5-100

plains grasslands	*Bouteloua* spp.	< 35
blue grama-needle-and-thread grass-western wheatgrass	*Bouteloua gracilis-Hesperostipa comata-Pascopyrum smithii*	< 35
blue grama-buffalo grass	*Bouteloua gracilis-Buchloe dactyloides*	< 35
cheatgrass	*Bromus tectorum*	< 10
California montane chaparral	*Ceanothus* and/or *Arctostaphylos* spp.	50-100 [95]
sugarberry-America elm-green ash	*Celtis laevigata-Ulmus americana-Fraxinus pennsylvanica*	< 35 to 200 [135]
paloverde-cactus shrub	*Cercidium microphyllum/Opuntia* spp.	< 35 to < 100 [95]
curlleaf mountain-mahogany*	*Cercocarpus ledifolius*	13-1000 [7,109]
mountain-mahogany-Gambel oak scrub	*Cercocarpus ledifolius-Quercus gambelii*	< 35 to < 100 [95]
Atlantic white-cedar	*Chamaecyparis thyoides*	35 to > 200 [135]
blackbrush	*Coleogyne ramosissima*	< 35 to < 100
northern cordgrass prairie	*Distichlis spicata-Spartina* spp.	1-3 [95]
beech-sugar maple	*Fagus* spp.-*Acer saccharum*	> 1000 [135]
California steppe	*Festuca-Danthonia* spp.	< 35 [95]
black ash	*Fraxinus nigra*	< 35 to 200 [135]
juniper-oak savanna	*Juniperus ashei-Quercus virginiana*	< 35
Ashe juniper	*Juniperus ashei*	< 35
western juniper	*Juniperus occidentalis*	20-70
Rocky Mountain juniper	*Juniperus scopulorum*	< 35
cedar glades	*Juniperus virginiana*	3-7
tamarack	*Larix laricina*	35-200 [95]
western larch	*Larix occidentalis*	25-100 [5]
creosotebush	*Larrea tridentata*	< 35 to < 100
Ceniza shrub	*Larrea tridentata-Leucophyllum frutescens-Prosopis glandulosa*	< 35 [95]
yellow-poplar	*Liriodendron tulipifera*	< 35 [135]
melaleuca	*Melaleuca quinquenervia*	< 35 to 200 [89]
wheatgrass plains grasslands	*Pascopyrum smithii*	< 35 [95]
Great Lakes spruce-fir	*Picea-Abies* spp.	35 to > 200
northeastern spruce-fir	*Picea-Abies* spp.	35-200 [34]
southeastern spruce-fir	*Picea-Abies* spp.	35 to > 200 [135]
Engelmann spruce-subalpine fir	*Picea engelmannii-Abies lasiocarpa*	35 to > 200 [5]
black spruce	*Picea mariana*	35-200
conifer bog*	*Picea mariana-Larix laricina*	35-200 [34]
blue spruce*	*Picea pungens*	35-200 [5]
red spruce*	*P. rubens*	35-200 [34]
pine-cypress forest	*Pinus-Cupressus* spp.	< 35 to 200 [5]

pinyon-juniper	*Pinus-Juniperus* spp.	< 35 [95]
whitebark pine*	*Pinus albicaulis*	50-200 [5]
jack pine	*Pinus banksiana*	<35 to 200 [34]
Mexican pinyon	*Pinus cembroides*	20-70 [87,126]
Rocky Mountain lodgepole pine*	*Pinus contorta* var. *latifolia*	25-300+ [4,5,107]
Sierra lodgepole pine*	*Pinus contorta* var. *murrayana*	35-200 [5]
shortleaf pine	*Pinus echinata*	2-15
shortleaf pine-oak	*Pinus echinata-Quercus* spp.	< 10 [135]
Colorado pinyon	*Pinus edulis*	10-49 [95]
slash pine	*Pinus elliottii*	3-8
slash pine-hardwood	*Pinus elliottii*-variable	< 35
sand pine	*Pinus elliottii* var. *elliottii*	25-45 [135]
South Florida slash pine	*Pinus elliottii* var. *densa*	1-5 [89,135]
Jeffrey pine	*Pinus jeffreyi*	5-30
western white pine*	*Pinus monticola*	50-200
Pacific ponderosa pine*	*Pinus ponderosa* var. *ponderosa*	1-47
interior ponderosa pine*	*Pinus ponderosa* var. *scopulorum*	2-10 [5]
Table Mountain pine	*Pinus pungens*	< 35 to 200 [135]
red pine (Great Lakes region)	*Pinus resinosa*	10-200 (10**) [34,38]
red-white-jack pine*	*Pinus resinosa-P. strobus-P. banksiana*	10-300 [34,55]
pitch pine	*Pinus rigida*	6-25 [24,56]
pocosin	*Pinus serotina*	3-8
pond pine	*Pinus serotina*	3-8
eastern white pine	*Pinus strobus*	35-200
eastern white pine-eastern hemlock	*Pinus strobus-Tsuga canadensis*	35-200
eastern white pine-northern red oak-red maple	*Pinus strobus-Quercus rubra-Acer rubrum*	35-200
loblolly pine	*Pinus taeda*	3-8
loblolly-shortleaf pine	*Pinus taeda-P. echinata*	10 to < 35
Virginia pine	*Pinus virginiana*	10 to < 35
Virginia pine-oak	*Pinus virginiana-Quercus* spp.	10 to < 35
sycamore-sweetgum-American elm	*Platanus occidentalis-Liquidambar styraciflua-Ulmus americana*	< 35 to 200 [135]
galleta-threeawn shrubsteppe	*Pleuraphis jamesii-Aristida purpurea*	< 35 to < 100
eastern cottonwood	*Populus deltoides*	< 35 to 200 [95]
aspen-birch	*Populus tremuloides-Betula papyrifera*	35-200 [34,135]
quaking aspen (west of the Great Plains)	*Populus tremuloides*	7-120 [5,46,85]

mesquite	*Prosopis glandulosa*	< 35 to < 100
mesquite-buffalo grass	*Prosopis glandulosa-Buchloe dactyloides*	< 35
Texas savanna	*Prosopis glandulosa* var. *glandulosa*	< 10 [95]
black cherry-sugar maple	*Prunus serotina-Acer saccharum*	> 1000 [135]
mountain grasslands	*Pseudoroegneria spicata*	3-40 (10**) [4,5]
Rocky Mountain Douglas-fir*	*Pseudotsuga menziesii* var. *glauca*	25-100 [5]
coastal Douglas-fir*	*Pseudotsuga menziesii* var. *menziesii*	40-240 [5,88,106]
California mixed evergreen	*Pseudotsuga menziesii* var. *m.-Lithocarpus densiflorus-Arbutus menziesii*	< 35
California oakwoods	*Quercus* spp.	< 35 [5]
oak-hickory	*Quercus-Carya* spp.	< 35 [135]
oak-juniper woodland (Southwest)	*Quercus-Juniperus* spp.	< 35 to < 200 [95]
northeastern oak-pine	*Quercus-Pinus* spp.	10 to < 35 [135]
oak-gum-cypress	*Quercus-Nyssa*-spp.-*Taxodium distichum*	35 to > 200 [89]
southeastern oak-pine	*Quercus-Pinus* spp.	< 10 [135]
coast live oak	*Quercus agrifolia*	<35 to 200 [5]
white oak-black oak-northern red oak	*Quercus alba-Q. velutina-Q. rubra*	< 35 [135]
canyon live oak	*Quercus chrysolepis*	<35 to 200
blue oak-foothills pine	*Quercus douglasii-Pinus sabiana*	<35 [5]
northern pin oak	*Quercus ellipsoidalis*	< 35 [135]
Oregon white oak	*Quercus garryana*	< 35 [5]
bear oak	*Quercus ilicifolia*	< 35 >[135]
California black oak	*Quercus kelloggii*	5-30 [95]
bur oak	*Quercus macrocarpa*	< 10 [135]
oak savanna	*Quercus macrocarpa/Andropogon gerardii-Schizachyrium scoparium*	2-14 [95,135]
shinnery	*Quercus mohriana*	< 35 [95]
chestnut oak	*Q. prinus*	3-8
northern red oak	*Quercus rubra*	10 to < 35
post oak-blackjack oak	*Quercus stellata-Q. marilandica*	< 10
black oak	*Quercus velutina*	< 35
live oak	*Quercus virginiana*	10 to< 100 [135]
interior live oak	*Quercus wislizenii*	< 35 [5]
cabbage palmetto-slash pine	*Sabal palmetto-Pinus elliottii*	< 10 [89,135]
blackland prairie	*Schizachyrium scoparium-Nassella leucotricha*	< 10

Fayette prairie	*Schizachyrium scoparium-Buchloe dactyloides*	< 10
little bluestem-grama prairie	*Schizachyrium scoparium-Bouteloua* spp.	< 35
tule marshes	*Scirpus* and/or *Typha* spp.	< 35 [95]
redwood	*Sequoia sempervirens*	5-200 [5,37,124]
southern cordgrass prairie	*Spartina alterniflora*	1-3 [95]
baldcypress	*Taxodium distichum* var. *distichum*	100 to > 300
pondcypress	*Taxodium distichum* var. *nutans*	< 35 [89]
western redcedar-western hemlock	*Thuja plicata-Tsuga heterophylla*	> 200 [5]
eastern hemlock-yellow birch	*Tsuga canadensis-Betula alleghaniensis*	> 200 [135]
western hemlock-Sitka spruce	*Tsuga heterophylla-Picea sitchensis*	> 200
mountain hemlock*	*Tsuga mertensiana*	35 to > 200 [5]
elm-ash-cottonwood	*Ulmus-Fraxinus-Populus* spp.	< 35 to 200 [34,135]

*fire return interval varies widely; trends in variation are noted in the species summary
**mean

POSTFIRE REGENERATION STRATEGY [123]:
Caudex/herbaceous root crown, growing points in soil
Ground residual colonizer (on-site, initial community)

FIRE EFFECTS

SPECIES: Lythrum salicaria

- IMMEDIATE FIRE EFFECT ON PLANT
- DISCUSSION AND QUALIFICATION OF FIRE EFFECT
- PLANT RESPONSE TO FIRE
- DISCUSSION AND QUALIFICATION OF PLANT RESPONSE
- FIRE MANAGEMENT CONSIDERATIONS

IMMEDIATE FIRE EFFECT ON PLANT:
Very little information exists describing the effect of fire on purple loosestrife, but indications are it does not burn readily [84,129].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
Reports of interactions between purple loosestrife and fire usually attest to the difficulty associated with trying to burn plants as a control method. Such attempts are commonly described as being confounded by moist soil conditions and patchy fuel distribution [81,84,102,129]. Because postsenescent purple loosestrife retains persistent standing dead stem material [14], it is possible that dry winter or early spring conditions may permit dense stands to carry fire, but this is speculative.

PLANT RESPONSE TO FIRE:
Although no direct evidence exists, it is likely that purple loosestrife will survive fire by sprouting from buds located below the soil surface on the root crown [47,113].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
No entry

FIRE MANAGEMENT CONSIDERATIONS:
The use of fire as a control measure for purple loosestrife largely has been dismissed as ineffective [81,84,129]. In large part, this has been due to typically wet soil condition where it occurs, combined with a well-protected rootstock from which it produces annual stem growth. Attempts to burn residual biomass following cutting or herbicide treatments, to the extent that material will actually combust, may merely result in recruitment of purple loosestrife seedlings due to exposure of bare substrate containing a substantial seed bank [118]. Rawinksi [102] compared the effects of burning following cutting with cutting alone on mean shoot density in a central New York wetland. Attempts to burn cut purple loosestrife stems were generally ineffective, although some dense clumps of cut material "burned rather completely." Reasons given for ineffectiveness of burn treatments were diffuse fuel arrangements, presence of substantial soil moisture, and the retention of moisture within cut materials.

MANAGEMENT CONSIDERATIONS

SPECIES: Lythrum salicaria

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Purple loosestrife shoots may be grazed by white-tailed deer [2,102], muskrat [2,129], and rabbits [2,112], but extent of mammal herbivory is sometimes difficult to determine due to rapid regrowth of multiple new stems from browse points. In a mixed stand of purple loosestrife and cattail, foraging muskrats were observed to occasionally cut stems of purple loosestrife but preferentially fed on roots and overwintering shoots of cattail [102].

While purple loosestrife invasion is often reported as detrimental to wetland-bird habitat, some evidence indicates little to no harmful effect. American coot, pied-billed grebe, black-crowned night heron, American goldfinch and gray catbird have all been observed nesting in purple loosestrife stands [2,102]. Red-winged blackbirds preferentially nest in purple loosestrife over cattails [101,142]. American goldfinch construct nests in purple loosestrife, utilizing the relatively stable stalks to attach nests above the ground or water surface [69]. Pied-billed grebes use dead purple loosestrife stems as nest substrate in habitat with standing and emergent vegetation [78]. In a 2-year survey of birds in wetlands surrounding Lake Huron's Saginaw Bay in eastern Lower Michigan, swamp sparrow nests were most abundant in areas of purple loosestrife dominance [142].

Although purple loosestrife, with its tiny seeds, has been assumed to provide little to no food for birds [129], there are several reports of ducks and red-winged blackbirds consuming purple loosestrife seeds [2], and a report of damage to experimental seedling plots in England caused by ring-necked pheasants and pigeons [112].

PALATABILITY:
No information

NUTRITIONAL VALUE:
No information

COVER VALUE:
Purple loosestrife stands may provide cover habitat for wood ducks [121], ring-necked pheasants and cottontail rabbits [120].

OTHER USES:
Purple loosestrife was previously used by European immigrants in herbal remedies for a variety of maladies [129]. Purple loosestrife, as well as other loosestrifes, have long been popular with gardeners for their abundant and attractive floral displays and are still sold legally in some places. However, many North American horticulturalists have now abandoned its promotion because of its potential for escape [15,35,49,60,83,129]. It has also been utilized as a honey plant by beekeepers [96,129]. Purple loosestrife seed has occasionally been included in commercial "wildflower" seed mixes [129].

IMPACTS AND CONTROL:
Impacts:
Purple loosestrife can be highly competitive, often reported as occurring in dense, monospecific stands, with the potential to dominate wetland plant communities where it occurs (see Successional Status) [1,42,66,67,79,129,136,137]. While it is evident that invading purple loosestrife may have harmful impacts on native flora and fauna, more research is needed to clarify the extent of these impacts. Hager and McCoy [48] and Anderson [2] provide critical reviews of literature describing purported negative impacts caused by purple loosestrife in North America. Both papers express concern that widespread claims of ecological harm caused by purple loosestrife are largely unproven. In a widely cited review of purple loosestrife literature in North America, Thompson and others [129] describe encroachment of purple loosestrife around the margins of a waterfowl impoundment in central New York. Their estimates of percent of total plant biomass contributed by purple loosestrife along dike areas of the impoundments describe "dramatic" increases over about a 15-year period. Based on visual estimates of plant biomass, the authors contend that native plant species were displaced, vegetation structure was altered, and habitat quality for nesting waterfowl was seriously degraded. The paper by Thompson and others [129] demonstrates how untested hypotheses can be perpetuated in the literature until they become widely accepted, without the benefit of experimental analysis [48]. As emphasized by Anderson [2], "detailed, quantitative data are needed to understand loosestrife's natural history, population dynamics, and impacts on native ecosystems if we are to effectively manage this plant."

Because purple loosestrife has demonstrated strong competitive abilities where it has invaded North American wetland communities, there is concern that it may diminish native plant diversity. For instance, competition with purple loosestrife has been suggested as a contributing factor in the decline of the rare Long's bulrush (*Scirpus longii*) in Massachusetts [28]. However, studies published to date have failed to demonstrate a deleterious effect of purple loosestrife on native plant diversity. Treberg and Husband [130] examined the association between purple loosestrife abundance and vascular plant richness along the Bar River in Ontario. Purple loosestrife had been present in this area for at least 12 years and there was a wide range in established plant densities. They found no significant ($P<0.05$) difference in mean species richness associated with the presence or percent cover of purple loosestrife, and no plant species was significantly ($P<0.05$) more likely to be found in the absence of purple loosestrife than in its presence. Anderson [1] showed no significant ($P<0.05$) correlation between total species richness and either percent cover, genet density or median age of purple loosestrife, even in plots containing 18-20 year old purple loosestrife plants. He suggested areas with apparent purple loosestrife monocultures perhaps had low species richness to begin with, and species richness more likely resulted from habitat heterogeneity rather than the presence of innately competitive species. More research is needed in this area.

Purple loosestrife colonization has been purported to have detrimental effects on birds, based on: a) creation of unsuitable nesting habitat and b) low food potential of purple loosestrife relative to vegetation it displaces.

However, published studies and observations indicate impacts on birds are not yet clear. Marsh wrens prefer cattails to purple loosestrife for nesting [101,142]. There is speculation that invasion of riparian areas in Nebraska may have adverse effects on important night-roosting habitat for migratory sandhill cranes. Purple loosestrife invasion is predicted to have detrimental effects on nesting habitat of black terns and canvasbacks in the north-central United States, but this has not been tested [129]. Whitt et al. [142] found purple loosestrife-dominated habitats had significantly (P=0.003) higher bird densities but significantly (P=0.03) fewer bird species than other habitats. These higher densities were mainly due to increases in populations of a single species, the swamp sparrow.

Purple loosestrife colonization can substantially reduce or eliminate open water in small marsh areas, potentially reducing its usefulness for waterfowl. In areas with substantial seed banks, mudflats that are commonly used as feeding areas by shorebirds are impacted by rapid, dense colonization by purple loosestrife seedlings. Decline in the extent of open water habitats from increased emergent purple loosestrife can retard access to aquatic prey items such as fish and aquatic invertebrates. Important aquatic food plants for wildlife such as pondweeds (*Potamogeton* spp.) are inhibited under the shade of emergent purple loosestrife [102]. Invading purple loosestrife in coastal British Columbia's Fraser River estuary may have negative effects on detrital food chains [45].

Thompson and others [129] have illustrated how muskrats might interact with purple loosestrife in a manner detrimental to muskrats. Muskrats apparently find stems of purple loosestrife much less palatable then those of cattail, but they do cut purple loosestrife stems. As they forage they favor cattail stems, potentially shifting the competitive balance toward the less palatable purple loosestrife. The ability of muskrats to shift the competitive balance between cattails and purple loosestrife was corroborated by Rawinski [102] from observations of mixed stands where muskrats were present. At a particular site, muskrats removed entire patches of cattail, leaving purple loosestrife the only remaining emergent. Muskrats may further favor purple loosestrife seedling establishment following den construction. This activity can cause substantial soil disturbance that is rapidly colonized by purple loosestrife seedlings during lower summer water levels. Because of their ability to generate new vegetative growth, partially eaten purple loosestrife stems also represent potential new propagules, adding to its competitive advantage [23]. As community composition shifts from cattails to purple loosestrife dominance, habitat quality and subsequent muskrat carrying capacity apparently decline [129].

Conversion of wetland pasture to predominantly purple loosestrife is believed to reduce forage value for livestock and deer [128]. As purple loosestrife density increases and mature plants produce greater numbers of shoots, the woody nature of purple loosestrife stems diminishes forage value [118].

Purple loosestrife may have adverse effects on habitat of the threatened bog turtle, although details are scant [26,68].

Purple loosestrife invasion may be detrimental to production of natural and domestic wild rice in areas of the upper Midwest, particularly in commercial wild rice paddy operations where water level manipulation presents ideal germination conditions. Dense purple loosestrife infestations can also undermine the functionality of drainage waterways, such as irrigation ditches [118].

Water level manipulations in impoundments have been hindered by threat of purple loosestrife invasion. A 1000-fold increase in acreage containing purple loosestrife was noted over a 23-year period in a central New York wetland and the cause was speculated to be recurrent drawdown of impoundments [102]. In areas managed for waterfowl production, such as many federal and state wildlife refuges, water level drawdowns in impoundments may provide establishment opportunities for purple loosestrife. Drawdowns are often executed to encourage recruitment of plants valuable to waterfowl such as cattails, smartweed (*Polygonum* spp.) and wild millet (*Echinochloa* spp.) on exposed soils [91].

Invading purple loosestrife is being monitored in the middle Snake River corridor in Idaho for effects on stream channel dynamics. Purple loosestrife is colonizing gravel bars under low flow conditions. Once established, it appears able to withstand inundation and flowing water conditions better than native annuals. It is feared that persistent purple loosestrife plants may contribute substantially to sediment trapping, leading to gravel bar aggradation, closure of small channels, and despoiling of secure, predator-free island nesting habitat for local waterfowl [33].

Control:

Land managers concerned about invasive purple loosestrife should focus on eliminating small, recently-established populations before tackling large, well-established populations. Buildup and persistence of purple loosestrife seed in the soil seed bank appears to be the most problematic, long-term obstacle in eradicating, or at least controlling purple loosestrife. Preventing seed production and seed bank accumulation within recently-established stands is a pragmatic goal, especially in the face of limited resources and knowledge [138,139]. Welling and Becker [138] demonstrated the potential difficulty managers face with attempts to exhaust seed banks in areas where purple loosestrife is well established, although not necessarily monodominant. Because seed dormancy is enforced by burial at relatively shallow (>0.8 inch (2 cm)) depth, and because purple loosestrife seed banks may contain thousands of seeds per square foot at these depths, even successful eradication of extant adult plants and new recruits from near-surface germinants may not suffice for successful long-term control. Even the ability to exhaust near-surface (<0.4 inch (1 cm)) seed banks by promoting germination and removing emergent seedlings is in question.

Any disturbance or management activity that fragments live stem or root tissue is likely to result in the spread, rather than containment of purple loosestrife [23,118]. Live stems that are dislodged and buried can give rise to new shoots via adventitious buds [23,129]. Carp may play an important role where they co-occur with purple loosestrife. Carp eat the roots of purple loosestrife, sometimes until the plants are dislodged and float away. These plants then become potential propagules if they lodge on suitable substrate [102].

Detection and control efforts may be hindered by purple loosestrife's propensity to occasionally remain dormant for an entire growing season. Some plants fail to generate aboveground shoots during a particular year, but exhibit normal growth from the same rootstock in preceding and following years [43,129].

Prevention:

It is important to avoid management activities that may enhance the risk of purple loosestrife invasion and expansion. Examples of mitigative efforts are a) encourage establishment, growth, or perpetuation of native woody cover that might provide enough shade to depress or discourage purple loosestrife, b) minimize water level fluctuations in manipulated wetlands or waterways that might encourage establishment of purple loosestrife seedlings, especially early-season drawdowns that expose bare substrate, and c) avoid any form of stress or disturbance to extant native plant communities in susceptible areas, such as disturbing soil with heavy machinery, and where such activities are unavoidable, monitoring impacted areas to detect invaders [129].

Periodic, systematic monitoring of susceptible habitats is strongly encouraged [144]. Development of local populations, as expressed by percent biomass constituted by purple loosestrife, is roughly a logistic function through time. Initial rate of spread of local infestations is slowed when extant competition is strong. As a result, early detection and eradication of colonizing plants is highly preferred. Fortunately, early detection is aided by the tall, showy flower stalks and lengthy period of bloom. Once purple loosestrife becomes strongly established, with many (>10) flowering stems per rootstock, multiple clumps forming monospecific patches or stands, and establishment of a seed bank, eradication becomes more expensive, intrusive, and difficult [129].

Spread of purple loosestrife in natural areas likely has been accelerated by the development, sale and use of various loosestrife cultivars for horticultural purposes. Sale and utilization of ornamental loosestrife cultivars should be curtailed to prevent the risk of further dissemination into previously uncolonized areas. Cultivars are capable of contributing viable seed and pollen to wild populations, and claims of sterile hybrids have been shown to be mainly false [3,75,93].

As with most invasive species, public education plays an important role in preventing establishment and spread of purple loosestrife. Planting of loosestrife cultivars for horticultural purposes should be strongly discouraged. Individuals who frequent areas susceptible to invasion can aid in prevention by washing boots, clothing, equipment, etc. before exiting such areas, and should be encouraged to identify and report potential new infestations to authorities.

Integrated management:

A single method may not be effective for long-term control or removal of purple loosestrife. Integrated management involves using several management techniques in a well-planned, coordinated and organized program. Many combinations of control methods can achieve desired objectives. Methods selected for a specific site will be determined by land-use objectives, desired plant community, extent and nature of infestation, environmental factors (nontarget vegetation, habitat types, climate, hydrology, etc.), economics, and effectiveness and limitations of available control techniques [103,114].

Cultural:

Seeding of competitive vegetation in areas where bare soil has been exposed may be a useful mitigative measure. This may be especially helpful where presence of seed in the soil seed bank indicates potential for robust purple loosestrife regeneration. Experiments examining the effectiveness of seeding Japanese millet (*Echinochloa esculenta*) to reduce the impact of purple loosestrife recruitment have shown mixed results [81,140]. In addition to providing competition against purple loosestrife seedlings, Japanese millet may be used by waterfowl and is thought to represent a minimal threat of invasiveness, although it is not native to North America [129]. Seeding native species may provide a desirable postdisturbance community, but explicit tests of the competitive abilities of various native plants when seeded with purple loosestrife are lacking. Seeding of competitors should take place immediately following exposure of soil to maximize their competitive abilities [81].

Flooding infested areas by raising water levels for extended periods may eliminate purple loosestrife from impoundment sites [47]. Flooding duration is more likely to influence mortality than depth of flooding, but specific guidelines are lacking [9]. Persistent high water conditions can slow the growth and reproductive capacity of purple loosestrife and over several years may eliminate extant stands, but results are variable and interactions with other factors poorly understood [81]. In plots subjected to consistently high water levels (16 inch (40 cm) mean depth)), competition with narrow-leaved cattail significantly ($P<0.001$) reduced stem densities of purple loosestrife compared with flooded stands where purple loosestrife was the predominant species [101]. More research is needed to determine optimal flooding duration and factors that influence variability in the effect of flooding duration [9].

Effectiveness of flooding as a control measure may be enhanced by cutting purple loosestrife stems prior to raising water levels [81]. Cut material should always be removed from the site to prevent spread of vegetative propagules. The efficacy of flooding may be influenced by the presence of carp within contiguous waterways, although the ultimate effects are unclear. Carp may reduce purple loosestrife by grazing its roots or enhance its spread by disseminating vegetative propagules [102]. Carp are not native to North America and should not be introduced as a means to control purple loosestrife.

Consistent spring and early-summer flooding may inhibit purple loosestrife seedling establishment [9,137]. Flooding seedlings 0.8 to 4 inches (2-10 cm) tall for 9 weeks at depths up to 12 inches (30 cm) did not significantly ($P<0.05$) reduce mean stem densities. Most plants continued to grow, if slowly, while submerged, and plants which emerged above the surface quickly resumed rapid growth [53]. Established purple loosestrife plants can survive in deepwater emergent habitat, in part by development of aerenchymous (containing large intercellular air spaces) stem tissue that facilitates gas exchange in aquatic environments.

Several factors may hinder the effectiveness of controlling purple loosestrife by flooding. Managers may be constrained in their ability to manipulate water levels by the geologic profile of the site or by development along its margins. Substantial warm season evaporation can contribute to this problem. Sustained high water levels may be detrimental to desirable native emergent or shoreline vegetation. Once purple loosestrife has been killed, managers should consider species composition within the remnant seed bank, and the ensuing colonizing community, when water levels have been reduced. It is likely that purple loosestrife seedlings will recolonize the newly exposed soil and further management may be inevitable.

Physical/mechanical:
Cutting stems or removing flower heads prior to seed dissemination can prevent local seed bank accumulation. Late-summer cutting appears to reduce vegetative growth more effectively than mid-summer treatments. However, cutting stems is unlikely to prevent perennial stem growth [47,102]. Cutting flower heads may be useful in preventing further seed production when primary control activities, such as herbicide application, require more than 1 season to completely eradicate purple loosestrife [13]. Cutting purple loosestrife stems underwater at various times in summer was ineffective [52].

Digging or hand-pulling plants is recommended for early infestations or a few scattered plants. Digging or pulling young plants in recently colonized areas can be effective in preventing establishment of dense, intractable stands and buildup of substantial seed banks. Early detection is important since established plants may rapidly become too large and deep-rooted for easy removal [102,129]. Because growing points of the plant are located on the root crown, removal of as much rootstock as possible is strongly encouraged [23,47]. Pulling entire plants is easiest when the soil is wet [102,131]. All pulled plant material should be removed from the site to prevent vegetative reproduction from discarded fragments [23]. Spot spraying individual plants with herbicide may be less time and labor intensive when infestations become too large for removal by pulling or digging [129].

Fire: See Fire Management Considerations.

Biological:
The objective of biological control is to re-establish ecological relationships that have evolved between purple loosestrife and its native predators in order to suppress invasive populations and reduce harmful impacts. Potential advantages of biological control are cost effectiveness at large scales, sustainability, and benign effects in the nontarget environment [22,131]. The Nature Conservancy's Weed Control Methods Handbook provides a comprehensive discussion of considerations and safety issues in developing and implementing a biological control program.

Plant communities where purple loosestrife is found are similar in North America and Europe. Because native insect herbivory inhibits purple loosestrife performance in Europe, it is hoped introductions of European insect herbivores may work to reduce the competitiveness of purple loosestrife in North America, while releasing native plants from suppression [18,19].

The following table lists non-native insects released in North America to control purple loosestrife:

Control Agent	Mode of Action	Release Sites
Galerucella calmariensis (beetle)	Larvae and adults feed on foliage and flowers	MB, ON
Galerucella pusilla (beetle)	Larvae and adults feed on foliage and flowers [18]	MB, ON, WA [29,32,97]
Hylobius transversovittatus (weevil)	Larvae and adults feed on roots [17]	WA [97]

Nanophyes marmoratus (weevil)	Larvae feed on flowers and adults feed on foliage and flowers [21]	MB [50]

Galerucella beetles have been the most effective biocontrol agents used against purple loosestrife in North America thus far [29,63,97]. *G. calmariensis* and *G. pusilla* are similar in appearance and habit and are most effective when released together, and both species appear to be unaffected by exposure to the herbicides glyphosate and triclopyr [76,77]. Because of "dramatic" success at some *Galerucella* release sites, release of other agents should focus on sites where *Galerucella* have been ineffective. In Europe, *H. transversovittatus* herbivory on purple loosestrife is strongest in the northern range of the plant, indicating that higher latitude sites may be a good choice for its release in North America [51].

Myzus lythri, a European aphid that has probably been present in the Eastern United States since the early 1930's, might become an effective biological control agent. It has a host-alternating life cycle, utilizing loosestrife and *Epilobium* spp. in summer and *Prunus* spp. as primary hosts the rest of the year. Populations of *M. lythri* could be manipulated to impact local purple loosestrife populations by mass-rearing bugs for targeted early-spring release and/or by planting *Prunus* spp. near targeted sites [134].

Research examining the potential use of pathogenic fungi as biocontrol agents is ongoing [92].

Chemical:

A variety of herbicides are effective at controlling purple loosestrife in infested areas. Below is a list of herbicides that have been used effectively against purple loosestrife in North America, as well as a brief discussion of important considerations regarding their use. This is not intended as an exhaustive review of chemical control methods. For more detailed information regarding appropriate use of herbicides in natural areas against this and other invasive plant species, see The Nature Conservancy's Weed Control Methods Handbook, as well as TNC's Wildland Invasive Species Program web page.

Chemical	Considerations
2,4-D [13,91,118,140]	Mixed results against purple loosestrife; harmful to dicots, but little impact on neighboring monocots
Triclopyr [12,39,62,90,118]	Generally effective at killing purple loosestrife; results are variable with spray volume; selective against dicots
Glyphosate [12,81,102,104,118,122,131]	Highly effective against purple loosestrife; specific formulations available for use in aquatic environments; also damages or kills most other plants which it contacts
Imazapyr [11]	Effective against purple loosestrife; negatively impacts cattail

A serious challenge to controlling purple loosestrife infestations with herbicides is preventing its re-establishment from the seed bank. In the presence of large purple loosestrife seed banks, removal of a considerable fraction of extant vegetation (weed or otherwise) can result in a dense monoculture of purple loosestrife seedlings. The result may be a worse infestation than was originally present [91]. Broadcast application of broad-spectrum herbicides, such as glyphosate, will likely result in widespread exposure of bare substrate and a dense, monotypic stand of purple loosestrife seedlings [118]. By carefully targeting glyphosate spray application to only purple loosestrife, damage to nontarget plants can be minimized. Continued careful treatments over several years can eventually reduce dense populations of purple loosestrife to minimal levels while promoting native plants [104,122]. Native plants are not just inherently valued, but can also provide competition against inevitable purple loosestrife recruitment from existing seed banks [118].

An apparent tradeoff exists when determining the best time to treat adult stands with herbicides. Managers must attempt to balance preventing seed production in established plants with treatments early in the growing season and preventing establishment of a viable new stand of purple loosestrife seedlings by delaying treatments long enough to inhibit recruitment. By conducting herbicide treatments on adult plants late in the growing season, newly established seedlings may not develop sufficiently to survive winter [90]. Late-summer herbicide application also appears to reduce negative effects on desirable native plants [81]. Rawinski [102] found that glyphosate application during late-bloom (mid-August in central New York) period, compared with late-vegetative (mid-June) period, resulted in fewer loosestrife seedlings the following season and increased presence of naturally established, beneficial plants such as shallow sedge (*Carex lurida*), rice cutgrass (*Leersia oryzoides*), smartweed and marsh seedbox (*Ludwigia palustris*). Late-season application of glyphosate in Minnesota wetlands tended to reduce cattail mortality compared with mid-summer treatments, perhaps because the onset of cattail senescence reduced herbicide uptake [12].

Another tradeoff exists between spray volume and target vs. nontarget effects. Purple loosestrife in Wisconsin was examined for response to variation in spray coverage of glyphosate (Rodeo at 1.5%). Individual genets were spot treated in mid-September and received either low (10-25% leaf area coverage), medium (40-60%), or high (75-90%) dosages. Reduction in adult purple loosestrife density was greatest in the high dosage treatment (90-100% reduction) and lowest in the low dosage treatment (75-90% reduction). Surviving purple loosestrife plants in all treatments were greatly reduced in size and vigor. Because glyphosate is nonselective in its effect, survival of nontarget vegetation was also closely related to dosage. High dosage treatment resulted in dense stands of purple loosestrife seedlings with little to no interspecific competition. In contrast, low dosage treatment resulted in high survival rates of desirable perennials and greatly reduced germination of purple loosestrife seedlings. Effective long-term control of purple loosestrife with glyphosate might best be achieved using low-dosage spot applications and conducting followup treatments in subsequent years as necessary [104].

To minimize non-target effects, managers in Michigan have developed a cut-and-herbicide method for purple loosestrife control. They propose cutting plants high on the stem (just below infloresence), allowing them to continue growing and better absorb the applied herbicide throughout the entire plant. Cutting too low apparently risks forcing the plant to "give up" on the leader and instead producing new ramets from the rootstock. Sponge applicators have been developed that limit contact between chemicals and nontarget plants [131]. These methods may be particularly useful in areas where mitigation of damage to indigenous species is important. Encouraging competition from extant native plants often helps reduce the vigor of invasives. For more detailed information regarding these methods, visit the TNC Wildland Invasive Species Program website: http://tncweeds.ucdavis.edu/esadocs/lythsali.html.

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