Solidago missouriensis, Missouri goldenrod 2020

Figure 1—Missouri goldenrod colony.
Photo by Peter M. Dziuk ©2014.

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ABSTRACT

Missouri goldenrod occurs in grasslands, shrub-steppe, and open and early successional woodland and forest throughout the Great Plains and the West. It is a perennial, clonal forb that spreads and regenerates from rhizomes that typically occur at depths of about 0.4 to 3 inches (1–8 cm) in the mineral soil, where they are likely insulated from the heat of fast-moving grassland fires. Missouri goldenrod is adapted to survive fire by sprouting from rhizomes and root crowns after top-kill. Smoldering fires in areas with high surface fuel loads may damage rhizomes and root crowns, although this is not described in the literature. It may establish from wind-dispersed seed or from seed in the soil seed bank after fire; however, seedling establishment seems rare.

Most of the available literature that provides data and observations on Missouri goldenrod response to fire are studies conducted in tallgrass prairie communities, with additional studies from fescue grasslands, oak and pine woodland and savanna, ponderosa pine communities, Oregon white oak ecosystems, and southern Arizona mountain shrubland. Much of the information on Missouri goldenrod response to fire is anecdotal.

Missouri goldenrod persists in plant communities with frequent—even annual—fires in most seasons. Many of the historical fire regimes in ecosystems where it is most common were characterized by frequent fires that occurred mostly during the growing season, but also in the dormant season. Differences in frequency, season, and severity of fire may affect postfire abundance of Missouri goldenrod, and these effects are likely to vary among plant communities, depending on the composition of associated species and their response to fire, as well as the frequency and intensity of grazing by wildlife and livestock. Some prairies and plains grasslands have a history of management with frequent prescribed fire, typically in spring, although precise timing and frequency vary, as does postfire plant community composition. Common objectives of prescribed burning in grasslands include increasing forage for livestock, reducing abundance of nonnative invasive plants, preventing establishment and spread of woody plants, reducing cover of woody plants, and increasing or restoring native plant diversity on the small, fragmented parcels that remain of these communities.

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INTRODUCTION

FEIS ABBREVIATION

SOLMIS

COMMON NAME

Missouri goldenrod

prairie goldenrod
smooth goldenrod
Tolmie’s goldenrod

TAXONOMY

The scientific name of Missouri goldenrod is *Solidago missouriensis* Nutt. (Asteraceae) (e.g., [1, 28, 42, 45, 49, 65, 69, 73, 78, 82, 94, 132]). Although most sources disavow varietal distinctions (e.g., [28, 42, 65, 69, 73, 78]), the following four varieties have been recognized by some authorities:

Solidago missouriensis var. *fasciculata* Holz., Missouri goldenrod [35, 45, 49, 80, 132, 159, 183]
Solidago missouriensis var. *missouriensis* Nutt., Missouri goldenrod [49, 132]
Solidago missouriensis var. *tenuissima* (Woot. & Standl.) C.E.S. Taylor & R.J. Taylor, Missouri goldenrod
Solidago missouriensis var. *tolmieana* (A. Gray) Cronquist, Tolmie's goldenrod [155]

Solidago missouriensis var. *fasciculata* was applied to tall, leafy-stemmed plants in the eastern part of the species’ range [27, 35, 45, 49, 183], and *S. m.* var. *missouriensis* was applied to shorter, often large-headed plants to the west [28, 49]. Plants from Arizona, Colorado, and New Mexico with long, linear leaves have been classified as *S. m.* var. *tenuissima* [42, 155], and large-headed plants with narrow bracts from prairies west of the Cascade Range in Oregon and Washington were sometimes classified as *S. m.* var. *tolmieana* [42, 68, 155]. However, Cronquist et al. (1994) did not find varietal distinctions useful [28], and Hitchcock and Cronquist (2018) no longer recognize varieties [69]. Heil et al. (2013) suggest that varieties are “strongly intergrading and without geographic integrity” [65].

This Species Review treats information on Missouri goldenrod at the species level unless otherwise indicated. Common names are used throughout this review. See table A1 for a list of common and scientific names of plant species discussed in this review and links to other FEIS Species Reviews.

SYNONYMS

Solidago glaberrima Martens [2, 103, 135]
Solidago missouriensis var. *extraria* A. Gray [33, 132]

LIFE FORM

Forb

DISTRIBUTION AND OCCURRENCE

GENERAL DISTRIBUTION

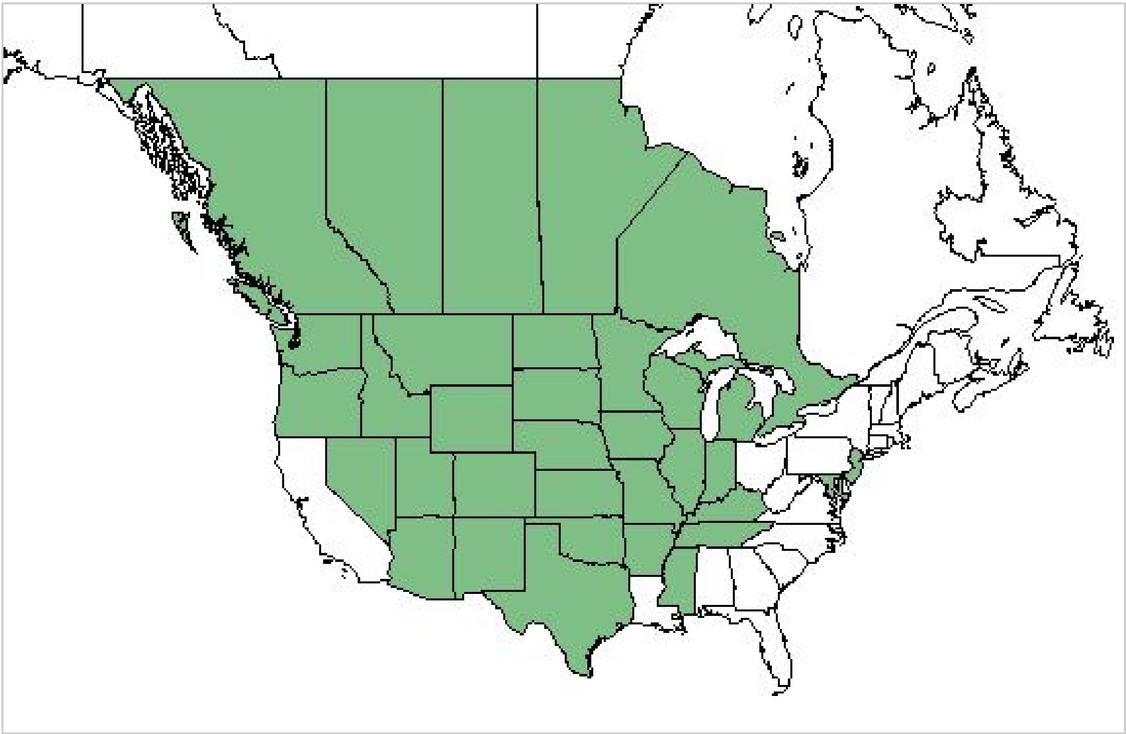

Figure 2—Distribution of Missouri goldenrod.
Map courtesy of the PLANTS Database (2019, 22 August) [155].

Missouri goldenrod is widespread and occurs from around 56° N latitude [132] in south-central and southwestern Canada, south into most of the Midwestern and western United States [111, 155]. It is most common in prairies and plains grasslands from southwestern Ontario and Minnesota, south to northern Arkansas and Texas, and west into the Rocky Mountains [94, 98]. It is less common east of the Mississippi River (e.g., [159]) and in the Intermountain West [28], and it is rare west of the Cascade Range [69]. In the southwestern United States, Missouri goldenrod is scattered to uncommon in Nevada [79] and the Four Corners region [65], and it is occasional in open forests and riparian areas in other parts of Arizona [40, 80, 104] and New Mexico [33, 34, 67, 121, 141]. Missouri goldenrod is probably not native in the Northeast, where it occurs in Maryland, Delaware, and New Jersey [155], and it was likely introduced to those places along railway lines [42].

States and Provinces
United States: AZ, AR, CO, ID, IL, IN, IA, KS, KY, MI, MN, MO, MT, ND, NE, NJ, NM, NV, OK, OR, SD, TN, TX, UT, WA, WI, WY
Canada: AB, BC, MB, ON, SK [105, 155]
Mexico (Coahuila) [42]

SITE CHARACTERISTICS

Missouri goldenrod most commonly occurs in grasslands and open wooded areas throughout the central and northern Great Plains [49]. It is a widespread and common to dominant species on dry, open slopes in upland prairies and plains grasslands [35, 45, 49, 132, 135, 138, 151, 170, 183]. It is occasional to frequent but not usually dominant in lowlands [1, 38, 135, 170] and other mesic sites [7, 29].

It is occasional in savannas, glades [183], open woodlands [7, 29, 45, 61, 94, 100], and in openings and margins of mesic to dry upland forests [183]. In the Pacific Northwest, it occasional in dry, open places east of the Cascade Range and rare in prairies west of the Cascade Range [69]. In the Southwest it occurs in open forests and riparian areas [17, 19, 65, 80], and in moist woods near seeps and springs in Nevada [79]. Throughout much of its range it is common in areas with disturbed soils such as gopher mounds [127], sand dunes [71], pastures and old fields, and along railroads, roadsides, ditches, and fences [42, 65, 94, 111, 135, 138, 183]. See Successional Status and Plant Response to Fire for more information on Missouri goldenrod response to disturbance.

Missouri goldenrod is moderately drought tolerant and most abundant in areas with 16 to 20 inches (406–508 mm) mean annual precipitation [164], but it occurs in areas with mean annual precipitation ranging from 12 to 35 inches (305–889 mm) [111, 182]. It occurs at elevations ranging from about 500 feet (152 m) in prairies, to over 7,220 feet (2,200 m) in the Rocky Mountain foothills [42, 182], and at montane [90, 94] and subalpine elevations (up to 10,600 feet (3,230 m) [111]) in the Rocky Mountains (table 1). In the Intermountain West it occurs from valleys and plains up to mid-montane elevations in the East Cascades [28, 69].

Table 1—Elevational ranges reported for Missouri goldenrod in some areas where it occurs.

Area	Elevational range
United States	
Great Plains, central	500–4,000 feet (152–1,219 m) [182]
Intermountain West	lowlands–8,200 feet (2,500 m) [28]
Southwest	5,300–8,500 feet (1,615–2,590 m) [19]
Arizona	5,000–9,000 feet (1,525–2,740 m) [17, 80]
Colorado	5,900–6,560 feet (1,800–2,000 m) [65]
Montana, northwestern	3,500–6,000 feet (1,070–1,830 m) [182]
Nevada	3,000–7,200 feet (900–2,190 m) [79]
Utah	5,000–8,120 feet (1,525–2,475 m) [175]
Uinta Basin	5,500–8,800 feet (1,680–2,680 m) [47]
Canada	
Alberta, southwestern	~3,000–7,500 feet (914-2,286 m) [182]

Missouri goldenrod grows best in well-drained soils with sandy loam to clay loam textures but tolerates both coarser and finer textured soils [111, 132]. In plains grasslands, Missouri goldenrod grows in deep loams and silty clay loams [93, 114, 164] formed in loess parent materials on level to steep uplands [93]. It occurs in sparse stands on sites with easily disturbed substrates such as gypsum sand dunes and shale outcrops [121]. It occurs on uplands, slopes, and lowlands with varied soil textures in tallgrass prairie (e.g., [38]) including floodplains [129]. In Nebraska Sandhills prairie, Missouri goldenrod occurs in deep, moist, sandy soil [61], on sand dunes [71], and in sand barrens [29].

Figure 3—Patch of Missouri goldenrod in rocky soil on a hillside near Bozeman, Montana, 5 August 2014. Photo by Matt Lavin.

In managed grasslands and remnant tallgrass prairies, Missouri goldenrod occurs in a range of soil types, from shallow to deep and from moderately well-drained [74] to poorly drained with high clay content [37].

In oak savannas and oak woodlands, Missouri goldenrod occurs on flat to rolling topography on sites ranging from sub xeric [107] or dry [7, 20] to wet-mesic on a variety of soil types. It occurs in full sun in moderately moist to dry soils [7], on dry, infertile sites [20], well-drained, nutrient-poor, sandy soils [116, 176], in sandy alluvium soil of river bottoms [46], and in rocky, limestone [107], and calcareous soils [7].

PLANT COMMUNITIES

Missouri goldenrod is predominantly a grassland species and is most widespread in prairie, plains grassland, and mountain grassland ecosystems. It also occurs in adjacent shrub steppe, savanna, and in some open or early-successional woodland and forest communities. Plant community composition, historical fire regimes, and postfire succession vary among these types.

Plant community composition of prairies and plains grasslands where Missouri goldenrod occurs varies with site characteristics (e.g., slope, aspect, soil type) and disturbance regimes including management history [9, 77]. Many of these grassland sites have been altered by cultivation, herbicide application, planting of nonnative species—especially cool-season grasses such as smooth brome and Kentucky bluegrass—livestock grazing, and annual mowing for hay; and some have been subsequently managed for restoration, including seeding of native species. Missouri goldenrod occurs in many of these disturbed grasslands (e.g., [37, 61, 114, 129, 130, 134, 146]), so it is often associated with nonnative and other "weedy" species [92, 136, 150]. It often occurs in pastures and grazed rangeland (e.g., [161]) and may increase with livestock grazing in native-dominated communities (e.g., [102]). However, it may be less common in cattle pastures planted with cool-season grasses and/or managed with broadleaf herbicides (e.g. [74]). See Old Field Succession for more information.

Grassland and Savanna

Missouri goldenrod is one of many important species of perennial forbs in **tallgrass prairie** communities, although forbs typically make up less than 10% of the total plant species composition [9]. Tallgrass prairie plant communities historically ranged from North Dakota and Minnesota southward to Oklahoma, including the sandhills of Nebraska and Flint Hills of Kansas. They are dominated by warm-season grasses such as big bluestem, little bluestem, Indiangrass, switchgrass, and prairie Junegrass [9, 61, 70, 88, 181, 182]. Plant community composition varies with differences in slope, aspect, and soil characteristics, which affect the amount and seasonal distribution of available moisture [9]. Missouri goldenrod is a common component of prairie communities in the Nebraska sandhills, where associates include other relatively xerophytic species such as prairie sandreed, needle and thread [178], white sagebrush, Cuman ragweed, and stiff sunflower [146].

Missouri goldenrod is a common and characteristic forb in **mixedgrass prairies** and **plains grasslands** throughout the Great Plains and Rocky Mountain foothills [10, 58, 61, 70, 88, 93, 99, 177], such as wheatgrass–bluestem–needlegrass communities that are transitional between bluestem prairie to the east and more arid grasslands to the west [179]. It is common in dry mixedgrass prairies dominated by blue grama, western wheatgrass, and needle and thread in the northern Great Plains from southern Alberta and Saskatchewan to eastern Montana and Wyoming [182]. Missouri goldenrod occurs in mixed grassland dominated by little bluestem, prairie Junegrass, and western panicgrass on sand barrens in Wisconsin [29] and easily disturbed substrates in east-central Montana [121]. Other dominant graminoids in plains grasslands include porcupine grass [88], sideoats grama [61, 93], switchgrass, eastern gamagrass [70], prairie sandreed, green needlegrass, needleleaf sedge [177], threadleaf sedge, and sun sedge [58]. Associated forbs in these communities may include purple prairie clover in Wisconsin [29], and plains milkweed, tarragon, rush skeletonplant, and upright prairie coneflower in Kansas [93].

Missouri goldenrod is a common component of **fescue grasslands** dominated by rough fescue, plains rough fescue, Altai fescue, and/or Idaho fescue. These occur in the northern Great Plains on sites where woody species can spread in the absence of fire, from the aspen parkland ecoregion in south-central Canada and the adjacent Rocky Mountain foothills southward into northwestern Montana [4, 50, 153, 182]. For example, Missouri goldenrod is a common forb in savanna-type habitats composed of a mixture of quaking aspen groves and rough fescue prairie in Alberta, along with common yarrow, fringed sagebrush, bastard toadflax, and prairie rose [91]. Idaho fescue, bluebunch wheatgrass, and Sandberg bluegrass are common codominants in Montana [102], northern Idaho [126, 165] and eastern Washington [31, 165].

At the northern extent of its range, Missouri goldenrod occurs in small areas (<7.4 acres (3 ha)) of dry grassland in the boreal zone at Wood Buffalo National Park in northern Alberta [131]. On the western side of the Cascade Range, Missouri goldenrod occurs in prairies associated with Oregon white oak ecosystems [55, 152]. For example, it was a component of the plant community composed primarily of Mediterranean grasses and weedy forbs on a site in western Washington formerly dominated by native prairie [120].

Shrub-steppe, Woodland, and Forest

Missouri goldenrod occurs in shrub steppe and woodland communities adjacent to plains grasslands such as Wisconsin brush prairie savanna with white sagebrush and New Jersey tea [12]. It occurs in creeping juniper/sun sedge, fragrant sumac/threadleaf sedge, Rocky mountain juniper/bluebunch wheatgrass, and quaking aspen/creeping barberry habitat types on the Custer National Forest [58]. At Theodore Roosevelt National Park, North Dakota, it occurs in silver sagebrush-western wheatgrass shrub steppe and Rocky Mountain juniper/littleseed ricegrass woodland [59]. It is a common component of pine and oak savanna, woodland, and open or early successional forest [7, 142] such as Wisconsin pine-oak savanna with jack pine and northern pin oak [158] and Wisconsin pine barrens with red pine and jack pine, where it is most frequent in early postfire succession [157]. It also occurs in bur oak-sumac scrub in the Black Hills, South Dakota [64] and chinquapin-mixed oak forests in central Tennessee, Kentucky, and southern Indiana [107].

Missouri goldenrod is one of the most common forbs in shrub steppe and woodland communities adjacent to mountain grasslands, such as shrubby cinquefoil-rough fescue habitat type in the Rocky Mountain foothills of western Montana [102, 163]. It occurs with sagebrush in intermountain basins in Colorado [173, 174], and with shrubs such as threetip sagebrush [31], common snowberry [43], and big sagebrush [184] in the shrub steppe zone of eastern Washington and Oregon.

Because it is a light-loving species, Missouri goldenrod is most common in openings, edges, and in early succession in woodland and forest communities. It occurs in twoneedle pinyon-juniper communities on the Gila National Forest in western New Mexico [67], and in Rocky Mountain juniper communities in north-central [125] and southeastern Montana and northern Wyoming [21, 86]. It is common in ponderosa pine communities in eastern Montana [21, 86, 125], northern Idaho [32, 57, 101], eastern Washington [32], eastern Oregon [140], Colorado [87], Arizona [40, 104], and New Mexico [33, 40]. In the ponderosa pine–Douglas-fir zone in the Colorado Front Range, Missouri goldenrod occurred on a site that was recently disturbed by brush clearing and cattle grazing [96]. Missouri goldenrod is a principal forb in quaking aspen communities in the Blue Mountains of Oregon [140], and it occurred under quaking aspen on burned sites 1 year after fire in an Engelmann spruce-lodgepole pine forest in Glacier National Park, Montana [98]. It also occurs within montane conifer forests in the Southwest [19] and in lodgepole pine-huckleberry communities in the Wallowa Mountains in Oregon [24].

Riparian

Missouri goldenrod occurs in riparian communities in Alberta [144, 145], Saskatchewan [143], North Dakota [59], Montana [60], Idaho [57], Utah [175], Arizona, and New Mexico [141]. Common dominants in these communities include narrowleaf cottonwood [60, 141], green ash [59, 60], narrowleaf willow [60, 145], and red osier dogwood [57, 60].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

BOTANICAL DESCRIPTION

This description includes characteristics that may be relevant to fire ecology and is not meant for identification. Identification keys for Missouri goldenrod are available (e.g., [28, 49, 69, 94, 183]). In the West, Missouri goldenrod may resemble small plants of Nevada goldenrod, and in the East, it can resemble early goldenrod; these species may be difficult to distinguish where their ranges overlap. Missouri goldenrod is distinguished by its usually three-nerved proximal leaves and its usually thin, elongated rhizomes. A number of Missouri goldenrod varieties have been described (see Taxonomy) based on differences in stem height, size and number of leaves, and inflorescence size and morphology [42]. Some of these differences are described below.

Missouri goldenrod is a warm-season, perennial and clonal forb with erect or ascending stems arising singly [28, 49, 79, 94, 183] or sometimes in small clusters [28, 49, 90, 94, 183] from creeping rhizomes [28, 49, 65, 94, 175, 183], or from an area variously described as “thickened” [103, 183], persistent and woody [90], a “woody base” [111], caudex [45], “woody caudex” [138], or “spreading caudex” [49]. Hereafter, this transition point between stems and roots will be referred to simply as the root crown.

Aboveground description: Stems are simple, rarely branched, and mostly range from about 12 to 31 inches (30-80 cm) tall [65, 69, 90, 138]. Taller plants (up to about 35 or 39 inches (90-100 cm) tall) occur mostly in the eastern part of the range, but occasionally west to Washington, and have been treated as *S*. *m*. var. *fasiculata* (e.g., [35, 45, 49, 132, 183]). Shorter plants (seldom more than about 20 inches (50 cm) tall) are described in the western part of the range (e.g., [28, 65, 79, 94, 175]), and these have been treated as *S*. *m*. var *missouriensis* (e.g., [28, 42, 132]). Two phenotypes of Missouri goldenrod clones were described in old fields on sandy soils in Minnesota: one with uniformly short stems (about 2-6 inches (5-15 cm) tall), and the other with uniformly tall stems (about 8-16 inches (20-40 cm) tall) [116].

Figure 4—Missouri goldenrod basal leaves. Photo ©2018 by Peter Dziuk.

Leaves are simple, alternate, somewhat thick and firm, and decrease in size up the stem [28, 38, 45, 49, 69, 94, 138, 183]. Lowermost, basal leaves range from about 2 to 12 inches (5-30 cm) long and 0.2 to 1.2 inches (0.5-3 cm) wide [28, 49, 111, 183], with median and upper stem leaves ranging from about 0.4 to 5 inches (1-13 cm) long [94, 175, 183]. Additional rosettes are sometimes present adjacent to the flowering stem [183]. Basal leaves may be persistent [28], early deciduous [45, 49], or withered to absent at flowering [183]. Basal and lowermost stem leaves are mostly deciduous on *S*. *m*. var. *fasiculata*, whereas those on *S*. *m*. var. *missouriensis* mostly persist [132].

Figure 5—Part of a Missouri goldenrod clone in Anoka County, Minnesota. Photo by Katy Chayka ©2012.

The inflorescence is a relatively dense panicle with numerous flowers on spreading or ascending branches in a pyramidal to ovoid shape, typically about 1 to 8 inches (3–20 cm) long and 1 to 5 inches (2.5-12 cm) wide [35, 42, 94, 138, 175, 183]. Fruits are cypselae, 1 to 2.2 mm long with a single seed bearing a 2.5 to 3 mm pappus [42, 69, 111, 138, 183].

Belowground description: Missouri goldenrod rhizomes are shallow (0.4-3 inches (1-8 cm) deep) [26, 103, 116], tough, and woody [26, 172], ranging from 1.5 to 8 mm in diameter [26, 79, 103]. Rhizomes are typically described as long [28, 65, 183], but may also have short, stout branches [28, 65, 183]. Maximum lengths of 8 inches (20 cm) [116], 12 inches (30 cm) [103, 172], and 17 inches (43 cm) [103] have been reported. Rhizomes grow from buds on both stem and root tissue. Studies of Missouri goldenrod rhizomes in Merrick County, Nebraska, found an average of about 6 rhizomes per stem. The longest rhizomes were 17 inches (43 cm), and average diameter was about 2.5 mm. Plants produced about 31 feet of rhizomes/ft^2 (104 m/m^2) in loam soil [103].

The root system is described as "rather superficial" [164], and most roots are fine (0.3-0.8 mm in diameter) and shallow [26, 139, 164, 172], with maximum density in the top 4 to 12 inches (10-30 cm) of soil [26, 139]. Some larger roots (over 1 mm in diameter) descend obliquely or vertically [26, 172] and can reach about 7 to 11 feet (2-3.4 m) deep [8, 139, 166, 172], indicating that this species does not rely on the surface soil layers for water and solutes. Lateral root spread is about 12 to 20 inches (30–51 cm) from the stem base [172]. Most roots were near the "thickened base" of stems, but may also occur at rhizome internodes [26, 103]. Abundance and length of laterals, and overall root depth varies with environmental conditions [26, 172]. In mixedgrass prairie in west-central Kansas, Missouri goldenrod tap roots were up to 6 feet (1.8 m) deep, and many "relatively fine laterals" occurred in the top 24 inches (61 cm) of soil [1]. Maximum depths reported from Kansas and Nebraska (~7-11 feet (2-3.4 m)) [8, 139, 166] were deeper than those recorded in Saskatchewan (1.4-4.3 feet (0.43-1.32 m)) [26]. Missouri goldenrod roots are colonized by arbuscular mycorrhizal fungi [14, 22, 63].

Clone structure and life span: A Missouri goldenrod clone (i.e., genet) is a discrete, compact group of asexually produced ramets (independent shoots and their associated roots) partly interconnected by rhizomes [100, 116]. Other plant species, primarily warm season grasses, often occur within a clone's "territory" (fig. 1, fig. 4). Shoots typically live for one growing season, and rhizomes persist for one or more growing seasons. Rhizomes that connect new ramets to parent plants persist about 3 years at most; however, Missouri goldenrod clones may live for several hundred years [100, 116] and can reach up to several meters across [38, 103]. Missouri goldenrod clones in Minnesota old fields ranged from 646 to 3,767 feet^2 (60-350 m^2) and were composed of 700 to 20,000 ramets [100]. Pure, dense stands in Nebraska had about 600 to 700 stems/m^2 [103]. In a Michigan old field, Missouri goldenrod clones in full sun were more than 50 years old and up to 8.2 feet (2.5 m) in diameter [176]. Life span of Missouri goldenrod clones in an Iowa prairie was thought to be 200 to 400 years or more—possibly up to 1,000 years (Whitham 1983 cited by [100]). Periods of prolonged dormancy might facilitate Missouri goldenrod longevity (see Vegetative Regeneration).

Raunkiaer [119] Life Form

Hemicryptophyte
Geophyte

SEASONAL DEVELOPMENT

Missouri goldenrod is a warm-season perennial that begins growth in early spring, flowers mostly in mid-summer (table 2), and senesces in early fall—September or October [46, 76, 97]—throughout much of its range. In some parts of its range, it flowers in early summer [138, 164] or in fall, from September through November [38]. According to Tolstead (1942), the flowers of many forbs, including Missouri goldenrod, appeared "after a heavy rain" in the northern Nebraska sandhills [146].

Plants often shed basal leaves after flowering, and seeds mature about 6 weeks after flowering [164]. At study sites in Kansas, most Missouri goldenrod seeds were collected in seed traps in late November (table 3).

Rhizomes initiate growth and elongate rapidly in middle to late summer, before aboveground stems die in fall [100, 116]. Buds develop at the ends of rhizomes in late August to early September, some of which emerge about 0.4 inch (1 cm) above the soil surface and produce a shoot with small leaves (~0.2-0.8 inch (0.5-2 cm) long). Stems grow from these emergent buds and belowground buds the following spring to early summer [4, 116, 164].

Table 2—Missouri goldenrod flowering dates reported by location.

Location	**Flowering dates**
North America	June–October [42, 111, 138]
United States	
Great Plains	July–October [49]
Four Corners region	August–September [65]
Arizona	June–August [80]
Kansas, west-central	late July–September [1]
Missouri	July–October [183]
Nevada	July–September [79]
Texas, north-central	July–October [35]
Canada	
Alberta, near Kinsella	by mid-July [91]

Table 3—Total number of Missouri goldenrod seeds collected in seed traps in native prairie and old field sites in Kansas [130].

Sample dates (month/day)	06/10	06/24	07/08–10/15	10/29	11/14	11/29	12/11
Number of seeds	1	3	0	11	149	211	111

REGENERATION PROCESSES

Missouri goldenrod is a clonal species that reproduces primarily asexually from spreading rhizomes and can form large colonies. New stems also sprout from rhizomes or root crowns following top-kill [1, 38, 91, 103, 138]. However, plants may remain dormant—with no aboveground growth for more than 10 years—after top-kill by defoliating beetles [100].

Missouri goldenrod also reproduces by seed [138]; however, information on sexual reproduction is lacking. Seed production and seedling recruitment rates are likely low because forbs with clonal growth forms generally allocate more resources to vegetative regeneration than to seed production [39, 91, 176]. Observations suggest that establishment of new (i.e., by seed) Missouri goldenrod clones (genets) is rare in undisturbed communities [116], and that establishment from seed is more likely in disturbed areas [100]. Successful establishment from seed is rare, but some seedlings survive [91], persist, and then spread vegetatively.

Vegetative Regeneration

Missouri goldenrod clones have extensive, branching rhizomes that grow horizontally in the mineral soil at depths of about 0.4 to 3 inches (1–8 cm) [26, 103], although rhizomes can also grow from greater depths. For example, rhizomes on plants buried by 3 to 6 inches (~8 to 15 cm) of soil ascended vertically, and new horizontal rhizomes were developing at depths of about 1 to 3 inches at the end of 1 year [103].

New shoots arise in spring from fall emergent buds (see Seasonal Development) and buds on underground rhizomes [116]. New rhizomes grow from buds on both stem and root tissue in late summer and fall [103].

Vegetative reproduction allows Missouri goldenrod clones to reach large sizes (see Botanical Description). Rhizomes may reach 8 to 17 inches (20–43 cm) long, allowing new ramets to establish this distance from parents, with greater distances (up to 24 inches (61 cm)) gained by rhizomes arising from roots [103]. Each ramet produces new rhizomes each year. In a Michigan old field, Missouri goldenrod ramets produced about 7 new rhizomes/year [176].

Rhizomes also store resources that may allow Missouri goldenrod to survive and sprout new stems following top-kill, and to persist during prolonged dormancy following top-kill from insects (e.g., [100]) or during severe drought (e.g., [168]). Following seasonal die-back or top-kill by disturbances such as fire or moderate insect defoliation, Missouri goldenrod reestablishes by sprouting from rhizomes and root crowns. Missouri goldenrod was among several native prairie forbs whose abundance increased, as cover of dominant grasses decreased, during an 8-year drought in the Great Plains (1933–1940) [2, 168]. These forbs “were sometimes practically the only species surviving over considerable tracts” [171]. Its abundance decreased as dominant grasses recovered afterward [168].

Missouri goldenrod response to damage from insect herbivory has been studied extensively at the Cedar Creek Natural History Area in central Minnesota (e.g., [20, 100, 116]), where Missouri goldenrod clones occur throughout a fire-maintained oak savanna remnant and four nearby old fields (abandoned from agriculture for more than 50 years). For example, Missouri goldenrod clones were completely defoliated and entered a period of prolonged dormancy after goldenrod leaf beetle (*Trirhabda canadensis*) populations erupted. None of the 24 Missouri goldenrod clones that were completely defoliated from mid-May through July produced ramets the summer after defoliation. Many defoliated clones recovered entirely or in part after 1 or more years of dormancy, but some were still absent above ground 10 years after top-kill. The factor signaling the breaking of dormancy among the physically disconnected rhizomes is not known, although it did not appear related to increased moisture after 3 dry years, because clones recovered in dry, normal, and wet years. Dormancy allowed clones to escape insect herbivory and eventually produce new ramets after the insects were extirpated from the clone’s territory [100].

Pollination and Breeding System

Goldenrods are insect pollinated and self-incompatible (Melville & Morton (1982) cited by [100]). Missouri goldenrod flowers are often visited by several bee species [138], including bumble bees [22].

Seed Production and Dispersal

Information on annual seed production by Missouri goldenrod is lacking. Seed production may differ between years and sites. For example, Missouri goldenrod may not flower and produce seed in years with inadequate summer rainfall [2], and seed production differed in plants growing in native prairie sites and plants growing in old field sites in Michigan (table 4).

Table 4—Annual average seed production and average seed weight of Missouri goldenrod in a 25-year-old field and a mature native prairie in Michigan [176].

Characteristic	Old field	Native prairie
Seed production (seeds/ramet)	4,200	1,100
Seed mass (µg)	17.6	39.3

Missouri goldenrod seeds are small and have a small pappus (fig. 6) that facilitates dispersal by wind [23, 117]. Estimates of annual seed rain from native prairie and old field sites in Kansas [130] and from an abandoned pasture site in a Saskatchewan grassland [72] had contrasting results. Missouri goldenrod seeds represented 3.6% of the total annual seed rain at 72 sample points in prairie plots and 1.7% in adjacent old field plots in a Kansas prairie (table 3), where it was a "common forb" in both areas (cover not given) [130]. Missouri goldenrod was not detected in the seed rain in or adjacent to plots where it occurred with about 1% cover in a Saskatchewan pasture that was cultivated and planted with wheat, Kentucky bluegrass, and smooth brome ~30 years prior [72].

Figure 6—Ripe seeds of Missouri goldenrod. Photo by Matt Lavin.

Seed Banking

Although Missouri goldenrod seeds have been detected in soil seed banks on some sites, it does not seem to form a persistent seed bank. Goldenrod seeds, in general, are small and do not persist in the soil seed bank (Root (1996) cited by [117]). However, Missouri goldenrod seeds have been detected in soil samples in Missouri tallgrass prairie [117], a Kansas prairie old field site [130], a Saskatchewan pasture [72], and a rough fescue prairie in Alberta [180], suggesting that it may survive for at least short periods in the soil seed bank on some sites.

Missouri goldenrod was a common component of the soil seed bank in a Missouri tallgrass prairie, and seedling emergence tests suggested a viable seed density of about 76 seeds/m^2 in the top ~4.7 inches

(12 cm) of soil [117]. No viable Missouri goldenrod seeds were detected (via seedling emergence tests) in seed bank samples from a tallgrass prairie site in Kansas, whereas Missouri goldenrod comprised 1.4% of the soil seed bank on an adjacent old field site. Missouri goldenrod was described as a "common forb" on both sites. The authors suggested that favorable conditions for germination were more common in the native prairie (due in part to regular burning) so viable seeds would have already germinated, and that conditions that promote seed dormancy and longevity were more common in old fields [130].

A study on the effects of grazing intensity on the composition of germinable seeds in the soil seed bank of a rough fescue prairie in southwestern Alberta found most germinable seed of Missouri goldenrod in litter samples from grazed sites, and few germinable seeds in mineral soil (table 5). On grazed sites, more seedlings emerged from litter samples taken in fall than spring (102 versus 0), but seedling emergence was similar among seasons on ungrazed sites (6 in fall, 8 in spring) [180].

Viable Missouri goldenrod seedlings emerged from seed bank samples collected from the top 2.8 inches (7 cm) of soil (2 seedlings/m^2, SE = 2) in a pasture in Saskatchewan, where it occurred with 1% cover. It was not detected in seed rain during the year of study [72].

Table 5—Average number of Missouri goldenrod seedlings that emerged in samples taken from a rough fescue prairie in southwestern Alberta. Surface litter samples were taken in fall from an area of ~290 cm^2, soil samples were taken in spring using an 87-cm^2 core to a depth of 6 cm and partitioned into 2-cm increments [180].

Depth (cm)	Ungrazed	Light and moderate grazing	Heavy grazing
Surface litter	6	93	214
0	12	1	0
0-2	2	0	3
2-4	2	0	0
4-6	0	0	0

Germination and Seedling Establishment

Information on Missouri goldenrod germination and seedling establishment is lacking. Germination rates are generally reported as low (e.g., [164]). Steiger (1930) observed Missouri goldenrod seedlings in 11% of plots (*n* = 100) in a tallgrass prairie in eastern Nebraska [135]; however, observations by other authors suggest that establishment of new Missouri goldenrod genets (i.e., by seed) is rare in undisturbed communities (e.g., [116, 120]). It may establish from seed on disturbed sites, especially with soil disturbance [100, 164]. However, little establishment was observed from Missouri goldenrod seed in seed mixes used for restoration of disturbed prairie in Washington [115].

Missouri goldenrod germination seems to be best on bare or disturbed (e.g., [120]) and moist (~50%–60% saturation) soil [15]. Blake (1935) found low germination rates (0%-12%) from dry-stored Missouri goldenrod seed and higher rates (37%) from seed that overwintered in moist soil in the field [15].

A study in a heavily invaded native prairie remnant in the Oregon white oak ecosystem in western Washington compared the effects of microsite availability (i.e., burn severity) and seed availability (0, 50, 100, and 200 seeds/species added) on seedling establishment. Missouri goldenrod seedling establishment was low, overall (mostly fewer than about 5 seedlings/plot). No seedlings established in unburned control plots, and establishment was greatest (mean of about 4 seedlings/m^2) on high-severity burn plots with low levels of seed addition (50 seeds/species/m^2), suggesting that Missouri goldenrod establishes best on bare ground with minimal competition for resources [120].

Missouri goldenrod seedlings may be sensitive to cold temperatures [103]. Rodents and grasshoppers may damage or kill Missouri goldenrod seedlings [164].

For information on Missouri goldenrod establishment from seed used for prairie and grassland restoration see Value for Rehabilitation of Disturbed Sites.

Plant Growth

Wasser (1982) described Missouri goldenrod seedling development as slow [164], whereas Blake (1935) described a 6-week old seedling with a main root >4 inches (10 cm) deep, with many, diffuse laterals (wide lateral spread) in top 10 cm of soil [15]. The first rhizomes that developed on Missouri goldenrod seedlings studied in Nebraska were offshoots from roots [103].

New ramets are produced from the apical tip of the overwintering rhizomes in spring and are not produced at the same node in successive years, so growth of the genet depends on the annual production of ramets [100]. See Botanical Description, Seasonal Development, and Vegetative Regeneration for more information on morphology and annual growth of Missouri goldenrod rhizomes.

Missouri goldenrod growth seems to be better on disturbed sites, where cover of other vegetation and competition for resources is reduced (e.g., [108]). Missouri goldenrod growth may be reduced by insects (e.g., [100]), leaf spots, rusts, and the parasitic plant, dodder (*Cuscuta* ssp.) in more humid regions [164]. Missouri goldenrod shoot biomass was about 50% greater in plots without root competition than those with root competition after 13 weeks of growth in a small-plot field study in quaking aspen-rough fescue savanna in the aspen parkland ecoregion of Alberta ($P < 0.0001$). Litter removal and activated carbon treatments (to limit root chemical interactions) had no significant effect on Missouri goldenrod shoot biomass with or without root competition [108].

Missouri goldenrod shoots are annual, but rhizomes are more persistent, with up to three generations connected. Insect damage to shoots of Missouri goldenrod can result in deterioration of rhizome connections, so that ramets from a given season are physically independent from ramets of earlier generations [100]. See Vegetative Regeneration for more information on effects of insect damage on Missouri goldenrod.

SUCCESSIONAL STATUS

Missouri goldenrod tolerates partial shade [164], but it generally grows best in full sun (e.g., [7]). It may establish in early succession from seed on disturbed soils, but generally establishes by sprouting from rhizomes and root crowns following top-killing disturbances. It persists into middle to late succession in grassland and savanna and open woodland (e.g., [20, 100]), and it is most common in early succession in forests (e.g., [140]). See the Plant Response to Fire section for more information on postfire succession.

Grassland and Savanna

Missouri goldenrod establishes from seed or rhizomes in disturbed soils and persists in mature grassland and savanna [100, 164], including sites with ongoing soil disturbance [71, 127]. It is likely to be more abundant and may become weedy with livestock grazing, because it is not highly palatable and therefore not usually eaten by livestock [102, 167, 169]. It may be less abundant in dense grassland [164].

Missouri goldenrod may be more abundant on grassland sites with ongoing disturbance. For example, Missouri goldenrod was among the most common species on gopher mounds and burrows on an upland tallgrass prairie site at Konza Prairie Biological Station, Kansas, and had similar frequency in undisturbed prairie plots and those on and adjacent to burrows and mounds [127]. It occurs in grasslands on sand dunes in Saskatchewan, where it is most frequent on stabilized blowouts (areas of recent, but not current, erosion), although it also occurs on active dunes and persists on stabilized dunes, depressions, and sand flats [71]. During an 8-year drought, Missouri goldenrod abundance increased on prairie sites as cover of dominant prairie grasses decreased [2, 168], and its abundance generally decreased as more mesic dominant grasses slowly recovered during 20 years of average and above-average precipitation that followed [168, 169].

Woodland and Forest

Missouri goldenrod is a common component of pine and oak woodlands in early to mid-succession and in open or early-successional forests [7, 20, 142]. For example, Missouri goldenrod was most frequent in early postfire succession in Wisconsin pine barrens [157], and it was common in mid-successional (20 to 30 years postdisturbance) oak savanna at the Cedar Creek Natural History area in east-central Minnesota [20].

In ponderosa pine communities on the Coconino National Forest, Arizona, Missouri goldenrod established on low-severity burned sites the summer after a May wildfire, and 2 years after fire it was one of the most abundant species on low-severity burned sites. It did not occur on high-severity burned sites and occurred with low abundance on unburned sites during the first 2 postfire years. Eight years after fire, it had established on high-severity sites, and its abundance decreased on low-severity and unburned sites. Thirty years after the fire Missouri goldenrod was not detected on any of these sites [11]. In the Colorado Front Range, Missouri goldenrod occurred in ponderosa pine communities disturbed by canopy removal [87], brush clearing, and cattle grazing [96]. In the Black Hills of South Dakota, Missouri goldenrod occurred in ponderosa pine stands that had been clearcut but not in thinned or unlogged stands [154]. Missouri goldenrod occurred under quaking aspen on burned sites 1 year after fire in a 200-year-old Engelmann spruce-lodgepole pine forest in Glacier National Park, Montana [98], and it was an early-seral species in grand-fir/thin leaf huckleberry communities in Oregon [140].

Old Field Succession

Several studies are available that examine succession on abandoned cropland and other restored grassland remnants. Management history on these sites is not always described, so they are difficult to compare. Missouri goldenrod is often present on these sites (e.g., [37, 74, 92, 114, 129, 130, 134, 136, 150]). It appears to establish naturally on many of these sites (e.g., [37, 83]), although it is also often included in native seed mixes used for restoration (e.g., [129]).

In the tallgrass prairie region of Kansas, a study of the floristics of 104 grasslands found that Missouri goldenrod was most frequent in warm-season hay fields that were dominated by native prairie species and cut annually for hay in July and August, and in old fields planted with warm-season natives and typically managed with periodic burning. It was rare to absent from areas planted to nonnative cool-season grasses and managed with broadleaf herbicides and/or cattle grazing [74]. Missouri goldenrod cover was not significantly different between native prairie sites (0.8%) managed with spring prescribed fires at 1- to 3-year intervals, and adjacent old field sites (0.1%–0.7%) undergoing prairie restoration (disked and sown with native warm-season grasses about 35 years prior to study and unmanaged thereafter) [83]. Missouri goldenrod occurred with 12% frequency and 1.4% mean cover in an area in Illinois that was previously cultivated, then abandoned. The area was left undisturbed except for occasional woody species removal (e.g., prescribed burns) over about two decades (1973-1993), and native tallgrass prairie species were allowed to naturally reestablish [37].

FIRE ECOLOGY AND MANAGEMENT

FIRE EFFECTS

Immediate Fire Effects on Plant

Fire top-kills Missouri goldenrod [149], but plants are likely to survive and sprout from rhizomes or root crowns if buds are not damaged (see Vegetative Regeneration).

Postfire Regeneration Strategy

Rhizomatous herb, rhizome in soil
Geophyte, growing points deep in soil
Ground residual colonizer (on site, initial community)
Initial off-site colonizer (off site, initial community)
Secondary colonizer (on- or off-site seed sources) [137]

Fire Adaptations

Missouri goldenrod is adapted to survive fire by sprouting from rhizomes and root crowns after top-kill [38, 103, 164], and may establish from wind-dispersed seed or from seed in the soil seed bank (see Regeneration Processes).

Rhizomes typically occur at depths of about 0.4 to 3 inches (1–8 cm) in the mineral soil, where they are likely insulated from heat generated by fast-moving grassland fires (e.g., review by [84]). Smoldering fires in areas with high surface fuel loads may damage rhizomes and root crowns, although this is not described in the literature.

Flowering and seed production may increase after fire [113], although response varies with frequency and season of fire [38] and information is generally lacking. In tallgrass prairie, Dornubush (2004) notes that flowering typically increases in late-flowering species after spring fires [36], and Pemble et al. (1981) indicate that flowering increased in Missouri goldenrod after a prescribed fire in May, but provide no data [113]. Missouri goldenrod plants on spring-burned plots had fewer flowers than those on summer burns; and plants on fall-burned plots had greater sexual reproductive effort than those on winter burns [38].

Plant Response to Fire

In general, Missouri goldenrod is likely to survive fire, and it persists in plant communities with very frequent—even annual—burning. Differences in frequency, season, and severity of fire may affect postfire abundance of Missouri goldenrod. These effects are likely to vary among plant communities where it occurs, depending on the composition of associated species and their response to fire. For example, timing of fire does not seem to strongly affect persistence or abundance of Missouri goldenrod in grasslands, although results may differ with topographic position in tallgrass prairies. Apart from several in-depth studies from the tallgrass prairie region, much of the information on Missouri goldenrod response to fire is anecdotal (i.e., mostly observations with few statistical comparisons).

Most of the available information about Missouri goldenrod response to fire comes from studies in tallgrass prairie communities (table A1). Most were conducted at the Konza Prairie Biological Station in Kansas [25, 30, 38, 62, 147-149], with three studies in Nebraska [18, 66, 181], two in North Dakota [75, 109], one in Minnesota [113], and one in Iowa [36].

Additional data and observations on Missouri goldenrod response to fire are available from several studies conducted in oak and pine woodland and savanna (table A3), five studies in fescue grassland in the aspen parkland ecoregion of Canada (table A4), six in ponderosa pine communities (table A5), two in Oregon white oak ecosystems in western Washington [120, 152], and one study in southern Arizona mountain shrubland [110].

Tallgrass prairie

See table A2 for details from fire studies conducted in tallgrass prairie communities that included data or observations on Missouri goldenrod. Several of these studies are summarized below.

In tallgrass prairie, Missouri goldenrod generally has a neutral response to fire in any season [18, 75, 109, 147], although some studies show changes in abundance with different combinations of fire frequency, season of burning, topographic position, and ungulate grazing. Observations at Kaslow Prairie State Preserve, Iowa, seem to differ from results in other tallgrass prairie studies. Missouri goldenrod occurred with 5% frequency in 1950, after several years of annual midsummer mowing. From 1950 to 1999, the area was managed with periodic spring (April) burning (approximately 2-9 years between fires), and Missouri goldenrod was not detected in 1999. The authors note that late-flowering species typically increase in abundance and flowering after spring fires, but this was not the case for Missouri goldenrod on this site [36].

Missouri goldenrod persists under a regime of frequent, even annual, prescribed fires in tallgrass prairie [25, 38, 148, 149], although it tends to be less abundant and smaller on annually burned sites compared to sites burned less frequently [25, 30, 38]. For example, on sites burned in spring at varying intervals, Missouri goldenrod plants were smaller and its cover was lowest on plots burned at 1-year intervals; its cover was highest on plots burned 20 years earlier, compared to those burned at 2-year and 4-year intervals [38].

Season of burning does not seem to have a strong effect on Missouri goldenrod abundance and reproduction in ungrazed tallgrass prairie, although results may vary with topographic position (i.e., lowland versus upland sites [18, 148, 149]). Missouri goldenrod cover was not different among plots burned annually in spring (April), summer (July), fall (November), and winter (February) for 2 years; however, plants on spring burns had fewer flowers than those on summer burns and were generally smaller than those on plots burned in other seasons, and plants on fall burns had greater sexual reproductive effort than those on winter burns [38]. After 14 years of annual burning in spring (April) and biennial burning in summer (July or August), Missouri goldenrod abundance “remained stable at low levels in the spring-burned watersheds” and "fluctuated with alternating intervals of decline and recovery over time in summer-burned sites". The only significant change in Missouri goldenrod abundance was on summer-burned plots on lowlands where it increased in both frequency and cover [149]. After 8 years of annual burning in fall, winter, or spring, Missouri goldenrod mean frequency increased on spring-burned lowland plots (reaching 52.5%) but was unchanged on all other plots (ranging from 27.5%-47.5%). Its mean cover remained the same on all lowland plots and on fall-burned upland plots (ranging from 0.3%-3.0%), but mean cover decreased to 0.4% on both winter-burned and spring-burned upland plots ($P < 0.05$) [148].

Grazing by cattle and especially by bison may have a substantial impact on Missouri goldenrod abundance on frequently burned tallgrass prairie sites, although information on this topic is sparse and results are inconsistent (e.g., [30, 62, 66, 147]). On ungrazed plots, Missouri goldenrod cover and frequency were unchanged with 10 years of annual burning; however, on plots grazed by bison or cattle, Missouri goldenrod cover and frequency increased significantly after 10 years of annual burning [147]. Missouri goldenrod response to grazing is complex and may vary with ungulate species, fire frequency, fire timing, and topographic position. For example, after 4 years of grazing by bison or cattle, Missouri goldenrod plants were shorter, while sexual reproductive effort, fruit production, and seed production were greater on grazed versus ungrazed plots, regardless of fire frequency. The effects of grazing on sexual reproduction were greater on plots burned at 1-year intervals than on those burned at 4-year intervals (table 6) [30].

Table 6—Growth and reproductive characteristics of Missouri goldenrod with grazing and burning treatments. Mean plant biomass, height, and number of flowers, seed heads, and seeds were determined for each population. SRE1 is the percentage of total shoot biomass in reproductive structures. SRE2 is the number of flowers per gram of plant biomass [30].

Fire interval	1-year		4-year	
Grazing regime	Grazed	Ungrazed	Grazed	Ungrazed
Biomass (g)	1.5	1.5	2	2.5
Height (cm)	27	30	35	45
SRE1	16	8	15	30
SRE2	40	30	35	25
Flowers	80	45	80	88
Seed heads	27	8	26	15
Seeds	390	75	375	250

Fescue grassland

See table A3 for details from fire studies conducted in fescue grassland communities that included Missouri goldenrod. Several of these studies are summarized below.

Information on Missouri goldenrod response to fire in fescue prairies of the northern Great Plains is limited to a handful of studies conducted in Saskatchewan [6, 50, 51] and Alberta [4, 16], some of which provide no statistical comparisons of Missouri goldenrod abundance on burned and unburned sites (e.g., [6, 16]), making results difficult to interpret and compare. Fescue prairies occur on sites where the environment supports shrubs and trees that can establish and spread in the absence of fire [4, 50, 182], and fire is often introduced as a restoration tool to reduce woody cover.

These studies and a review by Wright and Bailey [182], generally suggest greater abundance of Missouri goldenrod on recently burned than unburned sites [4, 50, 51]; however, this pattern is not consistent (e.g., [16]), and available data are insufficient to describe postfire response patterns with confidence. For example, at Camp Wainwright Military Reserve, Alberta, Missouri goldenrod was a “major increaser” after 25 years of annual spring burning in an Altai fescue prairie, while western snowberry and other woody species dominated unburned areas [3, 4, 182]. Missouri goldenrod increased more than any other forb with annual spring burning and had 50% mean frequency and 27% mean cover on burned sites compared to 18% mean frequency and 1.7% mean cover on unburned sites. Associated shrubs (especially western snowberry) increased in frequency but decreased in cover, and forest cover decreased from 68% to 15% after 25 years of annual burning [4]. After 3 to 5 prescribed fires over 8 years in forest transition communities dominated by quaking aspen in Prince Albert National Park, Saskatchewan, Missouri goldenrod abundance increased in the short term (when large, dominant grasses decreased), then decreased 2 to 12 years after fire (when woody species such as Saskatoon serviceberry and prickly rose increased), and increased again 12 to 27 years after fire [51]. The degree of change and reasons for increased abundance on long unburned sites were not apparent from the information given.

Pine barrens and pine-oak savanna

See table A4 for additional details from fire studies conducted in pine barrens and pine-oak savanna communities that include data or observations on Missouri goldenrod. Several of these studies are summarized below.

Missouri goldenrod is a common species in areas where tallgrass prairie transitions into pine-oak savannas and in jack pine barrens in the Great Lakes region, where combinations of soils, topography, and frequent fires historically maintained communities with scattered trees or open tree canopies, low shrub cover, and diverse understories [156, 157]. Missouri goldenrod was generally more frequent on burned than unburned sites in these communities, including frequently burned sites, but its abundance varied across study sites. For example, Missouri goldenrod persisted with frequent fires (2-19 fires over 20 years), and had a positive, but not significant relationship with fire frequency in an oak savanna community in Minnesota [142].

Although Missouri goldenrod persists with frequent fires, it also seems to tolerate long periods without fire in pine-oak savanna in Wisconsin. On a site in Crex Meadows, where jack pine and northern pin oak had grown into dense stands with 40% to 90% canopy cover (mean 77%) in long unburned sites, Missouri goldenrod had a similar mean frequency (12.3%) to areas recently burned with prescribed fires to restore prairie vegetation (12.9%). Woody species basal area was substantially less in burned than unburned areas [156, 158]. In another study at Crex Meadows that examined the effects of frequent fires on rodent populations and plant community composition, Missouri goldenrod was classified as an "increaser" because it was more frequent on sites burned 4 times over 15 years than on sites not burned for 35 years [12]. In Wisconsin pine barrens, Missouri goldenrod was consistently more frequent on recently burned sites than unburned sites. Across all four study sites its frequency was 7% greater on burned sites, on average ($P < 0.05$). Cover of woody species was lower on burned sites, and increases in frequency of understory plants were attributed to canopy opening [157]. Vogl (1961) studied several similar plant communities in Wisconsin where Missouri goldenrod was a common to dominant component of the understory, and he describes Missouri goldenrod variously—as fire neutral, an increaser, and a decreaser—based on differences in its frequency between burned and unburned sites in each community [158] (table A4).

Ponderosa pine and Southwest mountain shrub

See table A5 for details from the fire studies conducted in ponderosa pine communities that include data or observations on Missouri goldenrod. Some of these studies and are summarized below.

A few studies offer data and observations of Missouri goldenrod response to fire in ponderosa pine communities. Although this information is limited and mostly anecdotal, results from these studies seem to show little difference or somewhat greater abundance of Missouri goldenrod [44, 54, 128] in burned than unburned areas, suggesting that Missouri goldenrod is either unaffected by fire or that its abundance increases in response to canopy opening, such as after high-severity fire. For example, 9 years after the Rodeo-Chediski wildfire on the Apache-Sitgreaves National Forest, Arizona, Missouri, alpine, and/or threenerved goldenrods occurred on high-severity burned plots but not on moderate-severity burned plots [106]. In contrast, Missouri goldenrod was most abundant on low-severity burn plots 2 years after the Rattle Burn wildfire on the Coconino National Forest, Arizona. It occurred with low abundance on high-severity, low-severity, and unburned control plots 8 years after fire, but was absent from all plots 30 years after fire [11].

The short-term effects of a single spring prescribed fire in Arizona mountain shrubland on the Tonto National Forest dominated by Sonoran scrub oak and alderleaf mountain-mahogany were neutral to Missouri goldenrod. Its frequency, total biomass, and relative biomass were similar before and about 7 months after fire on both north and south slopes [110].

Oregon white oak savanna

Missouri goldenrod was among the most common species and had similar cover and frequency on both annually burned sites and sites burned at 3- to 5-year intervals in an Idaho fescue prairie in western Washington [152]. Seedlings established best on high-severity burned plots compared to low-severity and unburned plots on another prairie site in western Washington [120].

HISTORICAL FIRE REGIMES AND FUEL CHARACTERISTICS

Missouri goldenrod tolerates frequent fire in most seasons (see Plant Response to Fire), and many of the historical fire regimes in ecosystems where it is most common were characterized by frequent fires that occurred mostly during the growing season, and sometimes in the dormant season. Both grasslands and shrublands of the Great Plains region historically had frequent and widespread fires. For example, prairies and grasslands historically burned at 1- to 20-year intervals, and adjacent woodland and forest dominated by pines and oaks historically burned at about 18- to 30-year intervals [52]. Missouri goldenrod also occurs in early succession and in edges and openings in forests where fire is less frequent, such as high-elevation montane forests with historical fire intervals ranging from 100 to 300 years [98].

Historical Fire Regimes in the Great Plains

Historically, frequent fires played an important role in prairies and grasslands of the Great Plains by removing accumulated litter, stimulating native grass production, and impeding establishment and spread of woody plants and cacti. Abundance of forbs such as Missouri goldenrod was dynamic, responding to both fire frequency and timing, grazing by wild ungulates such as bison, and insect herbivory [84]. Throughout the Great Plains, estimates of historical fire intervals range from 1 to about 35 years (e.g., [112, 118, 162, 182]). Fire frequency varied with annual maximum temperature gradients from north to south and with annual precipitation gradients from east to west [53]. In tallgrass prairie ecosystems, historical mean fire interval estimates are 10 years or less, and in plains grasslands, mean fire interval estimates are 35 years or less [48, 112]. Historically most lightning fires occurred between May and September, especially July and August. American Indians set fires during both the growing season and the dormant season (both spring and fall) [84, 133]. Dormant-season fires tended to be complete (~100% consumption of biomass), and growing season fires nearly so (~80-95% of biomass consumed), suggesting that most fires were stand-replacement fires, as defined by LANDFIRE [48, 84]. See the FEIS Fire Regime publication about Plains Grasslands and Prairies for additional details and references on historical fire regime characteristics in grasslands of the central United States.

See these FEIS publications for additional information on historical fire regimes of plant communities in which Missouri goldenrod commonly occurs:

Midwest glades and barrens
Midwest oak savannas and woodlands
Northwestern Great Plains shrublands
Northwestern montane and foothill grasslands
Northern Rocky Mountain quaking aspen
Rocky Mountain Riparian
Oregon white oak

For historical Fire Regime information from other plant communities where Missouri goldenrod occurs, search for Fire Regime publications from the FEIS home page.

FIRE MANAGEMENT CONSIDERATIONS

Information specific to management of Missouri goldenrod with fire was not found in the literature as of 2020. However, several reviews are available that include information on contemporary conditions and associated fire management considerations in prairies and grasslands in the Great Plains (e.g., [84, 133, 182]). A brief summary of information from these and other recent literature is given below. See the FEIS Fire Regime publication for Prairies and Plains Grasslands for additional details and references on contemporary fire regime characteristics in grasslands of the Great Plains.

Some prairies and plains grasslands have a history of management with frequent prescribed fire, typically in spring, although precise timing and frequency vary, as does postfire plant community composition [182]. Common objectives of prescribed burning in grasslands include increasing forage for livestock, reducing abundance of nonnative invasive plants, preventing establishment and spread of woody plants, reducing cover of woody plants, and increasing or restoring native plant diversity on the small, fragmented parcels that remain of these communities [48, 84].

Timing of fire does not seem to strongly affect persistence or abundance of Missouri goldenrod in grasslands, although results may differ with topographic position in tallgrass prairie (see Plant Response to Fire). The role of phenology on postfire response may be stronger in grasslands than in other ecosystems, largely because fuel consumption and fire intensity do not vary much (but see [13]). Small differences in timing of spring fire may have large effects on postfire plant communities [5, 84]. Substantial variation in outcomes has been reported for burns conducted as little as 4 days to 3 weeks apart [84]. Timing of burning will have different effects on soil temperature and moisture, which can affect postfire succession (e.g., [84, 122]).

Several studies are available that include Missouri goldenrod and examine community-level responses to fires of varied frequency and timing (e.g., [50, 62, 75, 147, 148, 156, 158]).

OTHER MANAGEMENT CONSIDERATIONS

FEDERAL LEGAL STATUS

None

OTHER STATUS

Information on state- and province-level protection status of plants in the United States and Canada is available at NatureServe.

IMPORTANCE TO WILDLIFE AND LIVESTOCK

Missouri goldenrod is not highly palatable to wild ungulates [102], but may be occasionally grazed by bison [62, 95], deer [81, 138], and pronghorn [138]. It is used infrequently by small mammals and birds [164]. It is an important food for goldenrod leaf beetles [20, 100, 116].

Missouri goldenrod is grazed only sparingly by domestic cattle, and sheep [138, 164], and it may even be toxic to sheep [138].

Palatability and Nutritional Value

Palatability of Missouri goldenrod is considered poor for elk and fair for deer [102].

Palatability is poor for cattle and fair for domestic sheep [102, 164], and Missouri goldenrod is considered poor forage for livestock [164].

Cover Value

No information is available on this topic.

VALUE FOR REHABILITATION OF DISTURBED SITES

Missouri goldenrod can establish on disturbed sites [138, 164] with nutrient poor soils [116]. It tolerates weakly acidic to moderately basic and weakly saline soils [164], and it is moderately drought tolerant [85, 164]. Its extensive rhizome system allows it to spread quickly once established [103], and it may help stabilize soils on some sites [164]. However, it may become somewhat weedy once established [138, 164].

Missouri goldenrod is sometimes included in seed mixes used for revegetation and restoration of prairies and grasslands (e.g., [56, 115, 120, 164]). However, it may not establish well by seed (see Regeneration Processes), and Wasser (1982) recommends transplanting for better establishment [164].

OTHER USES

Missouri goldenrod is a traditional medicinal plant of American Indians, used to relieve sore throats and toothache. It is also an important species for honey production: the pollen is highly desirable to several bee species [138].

OTHER MANAGEMENT CONSIDERATIONS

Response to mowing

It can tolerate, and may even be enhanced by summer mowing, as demonstrated by its frequent occurrence on annually mowed hay fields (e.g., [36, 74]). Defoliation (e.g., by mowing or grazing) about one month before normal flowering may extend the flowering period [164].

Response to livestock grazing

Missouri goldenrod is one of many grassland forbs that increase in abundance under livestock grazing [5, 85, 102, 138, 146, 147, 161], because they are not highly palatable and therefore either not eaten or only sparingly grazed [102, 164, 167]. It may replace more palatable species that weaken or die with heavy grazing [89]. For example, in the montane region of Alberta, Missouri goldenrod is a dominant species in moderately to heavily grazed fescue grasslands [160] and in heavily grazed riparian narrowleaf willow stands [144]. See Plant Response to Fire for more details on Missouri goldenrod response to combinations of grazing and prescribed fire.

Response to herbicides

Several studies indicate that Missouri goldenrod is sensitive to damage from broadleaf herbicides (e.g., [123, 124, 150]).

Climate Change

Predicted changes in total annual precipitation in the Great Plains are inconsistent under different future climate change scenarios; however, soils are consistently predicted to become drier, and rainfall patterns are consistently predicted to become more variable, with fewer but larger rain events and longer intervals between them. The number of extreme precipitation events in the Great Plains has already increased markedly in recent decades (review by Jones (2017) [77]).

In an annually burned, ungrazed, native tallgrass prairie at Konza Prairie Biological Station, Missouri goldenrod, Canada goldenrod, little bluestem, big bluestem, and Indian grass accounted for 64% of the difference in plant community composition between plots exposed to ambient rainfall patterns and plots exposed to an altered regime with fewer but larger rainfall events and longer dry periods for 15 years. The altered regime resulted in significantly lower seasonal mean soil water content than ambient rainfall plots, and plants dominating plots with the altered regime were those more characteristic of drier sites. For example, abundance of Missouri goldenrod and little bluestem was greater, and abundance of Canada goldenrod, big bluestem, and Indiangrass was lower on plots exposed to the altered rainfall regime [77].

APPENDIX

Table A1—Common and scientific names of plant species mentioned in this review. Links go to other FEIS Species Reviews.

Common name	Scientific name
Trees	
alligator juniper	*Juniperus deppeana*
boxelder	*Acer negundo*
bur oak	*Quercus macrocarpa*
chinquapin	*Castanea pumila*
Douglas-fir, Rocky Mountain	*Pseudotsuga menziesii* var. *glauca*
Englemann spruce	*Picea engelmannii*
Gambel oak	*Quercus gambelii*
green ash	*Fraxinus pennsylvanica*
jack pine	*Pinus banksiana*
juniper	Juniperus spp.
lodgepole pine, Rocky Mountain	*Pinus contorta* var. *latifolia*
narrowleaf cottonwood	*Populus angustifolia*
northern pin oak	*Quercus ellipsoidalis*
ponderosa pine Arizona pine Rocky Mountain ponderosa pine	*Pinus ponderosa* *Pinus arizonica* *Pinus ponderosa* var. *scopulorum*
quaking aspen	*Populus tremuloides*
red pine	*Pinus resinosa*
Rocky Mountain juniper	*Juniperus scopulorum*
twoneedle pinyon	*Pinus edulis*
Shrubs	
antelope bitterbrush	*Purshia tridentata*
alderleaf mountain-mahogany	*Cercocarpus montanus*
big sagebrush mountain big sagebrush Wyoming big sagebrush	*Artemisia tridentata* *Artemisia tridentata* subsp. *vaseyana* *Artemisia tridentata* subsp. *wyomingensis*
common snowberry	*Symphoricarpos albus*
creeping barberry	*Mahonia repens*
creeping juniper	*Juniperus horizontalis*
fragrant sumac	*Rhus aromatica*
huckleberry	*Vaccinium* spp.
leadplant	*Amorpha canescens*
narrowleaf willow	*Salix exigua*
New Jersey tea	*Ceanothus americanus*
prairie rose	*Rosa arkansana*
prickly rose	*Rosa acicularis*

red osier dogwood	*Cornus sericea*
Saskatoon serviceberry	*Amelanchier alnifolia*
shrubby cinquefoil	*Dasiphora fruticosa* subsp. *floribunda*
silver sagebrush	*Artemisia cana*
Sonoran scrub oak	*Quercus turbinella*
sumac	*Rhus* spp.
threetip sagebrush	*Artemisia tripartita*
western snowberry	*Symphoricarpos occidentalis*
Graminoids	
Altai fescue	*Festuca altaica*
big bluestem	*Andropogon gerardii*
blue grama	*Bouteloua gracilis*
bluebunch wheatgrass	*Pseudoroegneria spicata*
eastern gamagrass	*Tripsacum dactyloides*
fescue	*Festuca* spp.
grama	*Bouteloua* spp.
green needlegrass	*Nassella viridula*
Idaho fescue	*Festuca idahoensis*
Indiangrass	*Sorghastrum nutans*
Kentucky bluegrass	*Poa pratensis*
little bluestem	*Schizachyrium scoparium*
littleseed ricegrass	*Piptatheropsis micrantha*
Medditerranean grass	*Schismus* spp.
needle and thread	*Hesperostipa comata*
needleleaf sedge	*Carex duriuscula*
plains rough fescue	*Festuca hallii*
porcupine grass	*Hesperostipa spartea*
prairie Junegrass	*Koeleria macrantha*
prairie sandreed	*Calamovilfa longifolia*
rough fescue	*Festuca campestris*
Sandberg bluegrass	*Poa secunda*
sideoats grama	*Bouteloua curtipendula*
smooth brome	*Bromus inermis*
sun sedge	*Carex inops* subsp. *heliophila*
switchgrass	*Panicum virgatum*
threadleaf sedge	*Carex filifolia*
western panicgrass	*Dichanthelium acuminatum* var. *fasciculatum*
western wheatgrass	*Pascopyrum smithii*
Forbs	
alpine goldenrod	*Solidago multiradiata*
bastard toadflax	*Comandra umbellata*

Canada goldenrod	*Solidago canadensis*
common yarrow	*Achillea millefolium*
Cuman ragweed	*Ambrosia psilostachya*
fringed sagebrush	*Artemisia frigida*
Maximillian sunflower	*Helianthus maximiliani*
plains milkweed	*Asclepias pumila*
purple prairie clover	*Dalea purpurea*
rush skeletonplant	*Lygodesmia juncea*
stiff sunflower	*Helianthus pauciflorus*
tarragon	*Artemisia dracunculus*
threenerved goldenrod	*Solidago velutina*
upright prairie coneflower	*Ratibida columnifera*
white heath aster	*Symphyotrichum ericoides* var. *ericoides*
white sagebrush	*Artemisia ludoviciana* subsp. *ludoviciana*
Ferns	
western brackenfern	*Pteridium aquilinum*

Table A2—Information from fire studies conducted in tallgrass or sandhills prairie that included data or observations of Missouri goldenrod response to fire.

Study location	**Objectives/Methods/Variables measured**	**Main findings related to Missouri goldenrod (MG)**	**Citation**
KS: Konza Prairie Biological Station	Compared cover of individual plant species and species richness on sites burned at 1-, 2-, 4-, and 20-year intervals Statistical comparisons were not made.	Mean cover of MG was lowest on 1-year plots (0.8%), followed by 20-year plots (1.4%), and 4-year plots (3.8%).	[25]
KS: Konza Prairie Biological Station	Compared cover, frequency, aboveground biomass, maximum plant height, number of tillers, number of flowers, and sexual reproductive effort (SRE) of 5 forb species on sites burned in spring at 1-, 2-, 4-, and 20-year intervals, and on sites burned by 2 fires in 2 consecutive years during spring (April), summer (July), fall (November), or winter (Feb) SRE was calculated in 2 ways: 1) reproductive structure mass/total aboveground mass, and 2) number of flowers/total aboveground mass.	• MG cover was lowest on 1-year plots and highest on 20-year plots. Cover was not different among plots burned twice in different seasons. • Plants were smaller and produced fewer flowers on 1-year plots, although plants on 20-year plots had the lowest SRE. • Plants on plots burned annually in spring were generally smaller than those burned in other seasons, and had significantly fewer flowers than those on summer burns. Plants on fall burns had greater SRE than those on winter burns.	[38]
KS: Konza Prairie Biological Station	Compared cover and frequency of individual plant species, diversity, richness, and biomass on ungrazed plots burned at 1-year intervals for 8 years in either fall, winter, or spring	• On lowland sites, MG cover did not change on plots burned in fall, winter, or spring. • On upland sites, MG cover did not change on plots burned in fall, but cover decreased ($P < 0.05$) on plots burned in winter and spring. • MG frequency increased on lowland sites burned in spring, but was otherwise unchanged. • MG mean cover was generally higher on lowlands (0.4%-3.0%) than uplands (0.3%-0.4%), and highest cover (3.0%) and frequency (52.5%) occurred on spring-burned lowland sites.	[148]

KS: Konza Prairie Biological Station	Compared trends in cover of individual plant species over 14 years on upland and lowland plots burned at 2-year intervals in summer (July-September) and on plots burned at 1-year intervals in spring (mid- to late-April) Summer fires were relatively low-intensity, slow-moving headfires impeded by high fuel moisture content. Spring fires had lower fuel loads than summer fires, but were relatively high-intensity and resulted in more complete combustion.	• Both frequency (from 41.6% in 1994 to 74.4% in 2007) and cover (from 3.5% to 14.0%) of MG increased significantly on summer burned plots on lowlands, but were otherwise unchanged. • MG abundance "fluctuated with alternating intervals of decline and recovery over time in summer-burned sites, but remained stable at low levels in the spring-burned watersheds (data not shown)."	[149]
KS: Konza Prairie Biological Station	Compared canopy cover of individual plant species on grazed pastures (bison and cattle) to nearby ungrazed sites Both grazed and ungrazed sites were burned at 1-year intervals.	• MG cover increased between 1995 and 2004 from 0.4% to 16.6% in bison pastures, 0.4% to 2.4% in cattle pastures, and did not change (3.1% to 0.6%) on ungrazed sites ($P < 0.05$). • MG frequency increased in bison pastures from 61.3% to 98.8% and in cattle pastures from 53.8% to 73.8%. Frequency on ungrazed sites did not change (35.0% to 25.0%; $P < 0.05$). • Perennial forb cover was greater in grazed pastures, due primarily to increased cover of MG and white heath aster.	[147]
KS: Konza Prairie Biological Station	Compared plant species abundance, composition, and diversity on sites grazed by bison for 4 years to ungrazed sites Sites were stratified by topographic position (upland and lowland). Half of the sites were burned at 1-year intervals and the other half at 4-year intervals.	• MG mean cover (0.01%) was lowest on grazed upland sites with a 4-year burn interval ($P < 0.05$). • MG mean cover was similar on all other sites: 0.7% on ungrazed sites with a 4-year burn interval, 0.4% on grazed and 0.6% on ungrazed sites with a 1-year burn interval.	[62]

KS: Konza Prairie Biological Station	Compared plant height, and total number of flowers, stems, seedheads, and seeds per plant in 5 forb species among treatments in a factorial combination of 3 grazing treatments (cattle, bison, and ungrazed) x 2 fire intervals (1-year and 4-year) x 2 replicates per treatment combination Plants were sampled 4 growing seasons after starting grazing treatments.	• MG plant height was lower, while sexual reproductive effort (SRE), fruit production, and seed production were greater, and total biomass was not different on grazed versus ungrazed sites. However, on 4-year fire interval sites, total biomass trended lower in grazed than on ungrazed sites. • Increases in MG SRE and fecundity with grazing were greater on sites burned at 1-year intervals than those burned at 4-year intervals. • MG plant height and total biomass trended lower on grazed and ungrazed sites burned at 1-year intervals than on those burned at 4-year intervals.	[30]
MN: Buffalo River State Park	Compared flowering in plots burned in a spring prescribed fire (May 1972) to unburned control plots on 6 site types in "badly disturbed" prairie	MG occurred on only 1 of the 6 site types (a nearly level, mesic site), and the authors report that its flowering activity “increased” after burning, although data are not provided.	[113]
ND: Sheyenne National Grassland	Compared plant species cover and biomass in plots burned under prescription in different seasons to control Kentucky bluegrass Treatments were: 1) burned 1x in summer (Aug 2014), 2) burned 2x in summer (Aug 2014 & 2017), and 3) burned 1x fall (Oct 2014). Data were collected before burning and for 1 to 3 seasons after burning.	MG had "a resilient positive response to burning", and Kentucky bluegrass had a strong negative response to burning. No additional species-level results were given.	[75]
ND: Tewaukon NWR	Compared cover on sites dominated by Kentucky bluegrass that were either burned in May, 2-4 years prior, or unburned for 10-15 years	MG cover was not different between burned and unburned plots.	[109]
NE: Nebraska National Forest	Compared soil and vegetation (cover and height) on burned plots 2-3 months after a May 1965 wildfire to unburned plots on 3 site types (dry valley, rolling sands, and choppy sands) in sandhills prairie	MG is listed as “increasing” at the 2 sandy sites and not listed among forbs occurring at the dry valley site; data were not provided.	[181]

NE: Niobrara Valley Preserve	Compared plant species cover before fire and 4 years after a single spring (May), summer (July), or fall (October) fire on 3 site types (hilltops, southern aspects, and northern aspects) and categorized species as fire-neutral, fire-positive, or fire-negative	• MG was "generally unresponsive to burning" and categorized as a fire-neutral species. • MG cover did not differ among sites burned in different seasons on any topographic location. • On hilltops, MG cover on unburned controls (7%) was significantly greater than cover on burned sites (3% spring, 2% summer, 2% fall).	[18]
NE: Stolley Prairie and Bauermeister Prairie	Compared plant frequency among 4 simulated grazing and burning treatments: simulated grazing+burn, simulated grazing+unburn, ungraze+burn, ungraze+unburn Simulated grazing consisted of hand clipping and litter removal at 3 levels (i.e., fuel loads). Burning was in April 1990, and vegetation was sampled throughout the growing season of that year.	MG was infrequent to absent overall (0-3 occurrences/plot) in all treatments at both sites; no patterns were apparent.	[66]

Table A3—Information from fire studies conducted in fescue grasslands that included data or observations of Missouri goldenrod response to fire.

Study location	**Plant community and site characteristics**	**Objectives/Methods/Variables measured**	**Main findings related to Missouri goldenrod (MG)**	**Citation**
AB: Camp Wainwright Military Reserve	Altai fescue prairie in aspen parkland Sites had history of burning, but had minimal grazing, browsing, or other disturbance.	Compared plant species cover and biomass on burned and unburned areas after 25 years of burning at 1-year intervals in early spring (April)	• MG mean cover was 27% on burned versus 1.7% on unburned sites. • MG mean frequency was 50% on burned versus 18% on unburned sites. • MG abundance increased more than any other forb.	[4]
AB: southwest of Granum	Mid- to late-successional plains rough fescue-Parry's oatgrass communities burned by wildfire in December 1997	Compared plant cover on burned sites (1-3 years after wildfire) to paired unburned sites Statistical comparisons were not made.	• MG cover was 0.1% in burn perimeter, and 0% in the burn interior and unburned sites 1 year after fire. • MG cover was 2.8% in perimeter, 0.7% in interior, and 0.9% in unburned sites 2 years after fire.	[16]
SK: Kernen Prairie	Plains rough fescue prairie with western snowberry, roses, and Kentucky bluegrass, last burned in May 1991	Compared density of forbs and shrubs and cover of graminoids in an unburned plot to those on plots burned by a single spring, summer, or fall prescribed fire (in 1998), 2 growing seasons after fire Statistical comparisons were not made.	• MG density was 0.3 stems/m^2 on the unburned site, 0.3 stems/m^2 on the spring burn, 11.0 stems/m^2 on the summer burn. It was not detected on the fall burn.	[6]
SK: Kernen Prairie	Plains rough fescue prairie Portions of the site were grazed or hayed "periodically" since 1967, and experimental fires have been conducted on several sites since 1986.	Compared cover of individual species on sites burned 1 time in 90 years to that on sites burned 3 times in 11 or 12 years to that on unburned sites (>90 years or >12 years since fire, respectively) Vegetation was sampled annually for 6 years after the last fires, which were conducted in all months of the year except January or February.	• MG was an indicator of sites burned 1 time ($P < 0.001$).	[50]

SK: Prince Albert National Park	Plains rough fescue prairie and prairie-forest transition communities dominated by quaking aspen; area grazed intermittently by bison and elk; last known fire ~1947; fires actively suppressed since 1960	Compared species mean frequency (number of quadrats/plot) and mean cover across all plots in each community (grassland and forest-transition) before burning (in 1975) to that on plots burned 3 or 5 times in fall or 4 times in spring over an 8-year period (1975-1983); postfire surveys conducted in 1983, 1995, and 2010.	In both grassland and forest transition communities, MG mean frequency and cover increased 1-3 years after the last fire, decreased over the next 8 years as woody cover increased, and then increased over the next 5 years.	[51]

Table A4—Information from fire studies conducted in pine barrens and pine-oak savannas that included data or observations of Missouri goldenrod response to fire.

Study location	**Plant community**	**Objectives/Methods/Variables measured**	**Main findings related to Missouri goldenrod (MG)**	**Citation**
MN: Cedar Creek Natural History Area	Oak savanna converted to forest with fire exclusion; Prescribed fire program implemented in 1964	Compared plant cover at 9 sites burned by prescribed fires of varied frequency applied over a 20-year period (2 to 19 fires over 20 years) to that on 3 unburned sites	A linear regression showed no relationship between MG cover and fire frequency ($P < 0.10$).	[142]
WI: Crex Meadows	Red pine-jack pine-oak savanna transitioning to woodland; partially closed stands (40%-90% cover, mean=77%) and increased cover of woody species (mostly jack pine and northern pin oak) with fire exclusion	Compared species frequency on sites burned 1-4 times (sampled the same year or 1-2 years after fire) to that on unburned sites; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was 12.9% on burned sites versus 12.3% mean frequency on unburned sites. • MG classified as “neutral”	[156, 158]

WI: Crex Meadows	"Pine island" stands	Compared species frequency in stands burned 1-6 times (mean = 3.5 fires/stand) to that in unburned stands; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was 12.3% greater in burned versus unburned stands. • MG classified as "increaser"	[158]
WI: Nicolet National Forest	"Bracken grasslands" in upland openings surrounded by second-growth pine-hardwood forest, where Missouri goldenrod was a ground-layer dominant along with western brackenfern and little bluestem	Compared species frequency on recently burned sites (same year or 1 year after) to that on unburned sites; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was 19.7% on burned sites versus 31.2% on unburned sites. • MG classified as "decreaser"	[158]
WI	Pine-barrens transitional forest dominated by jack pine; historically savannas before fire exclusion	Compared species frequency on recently burned sites to that on unburned sites; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was 1% lower on burned versus unburned sites. • MG classified as "neutral"	[158]
WI	Northern pine hardwood forests without history of frequent fire; openings close rapidly after burning	Compared species frequency in recently burned stands to that in unburned stands; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was 13% higher in burned versus unburned stands. • MG classified as "increaser"	[158]
WI	Southern xeric oak forest; white oak, black oak, and Hill's oak before wildfire	Compared species frequency in recently burned stands to that in unburned stands; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was 5% lower in burned versus unburned stands. • MG classified as "decreaser"	[158]

WI: Crex Meadows WMA	Northern pin oak-jack pine savanna ("brush prairie savanna") at ecotone with tallgrass prairie (big bluestem, little bluestem, sedges, and nonnative Kentucky bluegrass)	Compared species frequency on burned (2, 4, or 11 times in spring during past 15 years) and unburned areas (not burned for 35 years) and assessed effects of spring fires on rodent populations; classified species response to fire (increaser, decreaser, or neutral)	• MG mean frequency was >25% higher in areas burned 4 times over 15 years versus unburned areas. • Mean frequency between burned and unburned areas differed by <25% after other burning treatments. • MG classified as “increaser”	[12]
WI: Namekagon River Barrens (NRB), St Croix-Bois Brule River Barrens (SCBB), Manitowish River Barrens (MRB)	Pine barrens and pine-hardwood communities dominated by red pine and jack pine	Compared species frequency in 3 recently burned and paired unburned sites: • NRB was burned in spring for 1 or 2 successive years and measured in the same year or 1 year after fire; • SCBB sites were either burned once in spring and sampled the same year or burned twice and sampled a year after the last burn; and • MRB was burned by spring wildfires and sampled the next year.	• NRB: MG absent from unburned plots, 17% frequency on burned plots • SCBB: MG had 23% frequency on unburned plots, 27% on burned plots • MRB: MG had 21% frequency on unburned plots, 32% on burned plots • Across all sites, mean MG frequency on burned plots was 7% higher than on unburned plots ($P < 0.05$).	[157]

Table A5—Information from fire studies conducted in ponderosa pine communities that included data or observations of Missouri goldenrod response to fire.

Study location	**Objectives/Methods/Variables measured**	**Main findings related to Missouri goldenrod (MG) and other goldenrod species**	**Citation**
AZ: Rodeo-Chediski Fire, Apache-Sitgreaves National Forest	Compared plant community composition on sites burned at moderate severity to that on sites burned at high severity 9 years after the 2002 wildfire	Missouri, alpine, and/or threenerved goldenrods occurred on high-severity burned plots but not on moderate-severity burned plots.	[106]
AZ: Rattle Burn Fire, Coconino National Forest	Compared understory composition and biomass on high-severity and low-severity burned plots and unburned plots after the 1972 Rattle Burn wildfire; vegetation sampled in 1972, 1974, 1980, 2002, 2003	• MG occurred only on low-severity burned plots and was an "indicator" of low-severity fire in 1972. • MG reached greatest abundance and was one of the 5 most productive species on low-severity burned plots in 1974; MG also occurred on unburned sites but was absent from high-severity sites. • MG occurred on all site types in 1980. • MG was absent from all sites in 2002 and 2003.	[11]
AZ: Fort Valley Experimental Forest	Compared species cover before and 1-2 years after prescribed burning; sites had not burned for ~75 years	*Solidago* spp. (MG and threenerve goldenrod) cover was "significantly lower" on burned plots compared to prefire cover, 1 and 2 years after burning.	[41]
CO: Arapaho-Roosevelt National Forest	Compared species frequency and density (units not given) before 2 prescribed fires (1975 and 1976) and 1-2 years after fire; postfire sampling conducted in 1976 and 1977 at Eagles Cliff and in 1977 at Mill Creek	• Eagle Cliff: MG frequency was 12% before fire, 39% in postfire years 1 and 2; MG density was 0.45 before fire, 3.31 in postfire year 1, and 3.20 in postfire year 2. • Mill Creek: MG frequency was 88% before fire, 92% in postfire year 1; MG density was 8.50 before fire and 7.83 in postfire year 1.	[128]

NM: Las Conchas Fire, Jemez Mountains	Compared prefire to postfire satellite imagery to calculate degree of postfire change and classify sites as either refugia (unburned or low-severity burned areas) or non-refugia (moderate- to high-severity burned areas), and used vegetation surveys with field data to characterize refugial plant communities	MG occurred at field sites where the density of refugia was low to moderate and was not characteristic of refugial plant communities, suggesting that it was more common in burned than unburned areas.	[54]
SD: Black Hills, Hart Ranch	Compared frequency of understory species 6 months before and 4 months after a mid-April prescribed surface fire (1971) in a fire-excluded stand	MG frequency increased on both unburned and burned plots, from 3% and 2% before fire to 17% and 28% after burning, respectively.	[44]

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