Melilotus alba, M. officinalis

INTRODUCTORY

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FEIS ABBREVIATION:
MELALB
MELOFF

NRCS PLANT CODE [256]:
MEOF

COMMON NAMES:
white sweetclover
yellow sweetclover

TAXONOMY:
Sweetclovers are part of the *Melilotus* (Fabaceae) genus. While some systematists treat white sweetclover (*Melilotus alba*) Medik. and yellow sweetclover (*Melilotus officinalis*) (L.) Lam as distinct species ([116,231], Isely 1990 cited in [48]), others suggest they are not distinct and recognize only one species, *Melilotus officinalis* ([256], van der Meyden personal communication cited in [268]). Other systematists suggest recognizing both species, since they have been identified as such for over 200 years [268], and Barneby [11] reports that the 2 species are genetically incompatible.

This review treats yellow and white sweetclover as individual species. "Sweetclover" is used when citing information common to both species.

There are many sweetclover cultivars. Information about cultivars is available in the following references: [219,273,285].

SYNONYMS:
For *Melilotus alba* Medik.:
Melilotus albus Desr. ex Lam [117,158,169,282]
Melilotus albus Medik [48,151,278,298]

LIFE FORM:
Forb

DISTRIBUTION AND OCCURRENCE

SPECIES: Melilotus alba, M. officinalis

- GENERAL DISTRIBUTION
- HABITAT TYPES AND PLANT COMMUNITIES

GENERAL DISTRIBUTION:
Sweetclover is nonnative throughout North America. Eurasia [10,98,101] and, more specifically, the Mediterranean region from central Europe to Tibet [55,188], is the native range for sweetclover.

Although widely and similarly distributed in the United States, yellow and white sweetclover are considered most common in the upper Midwest and Great Plains regions [45,115]. In the West, yellow sweetclover is rare west of the Cascades [101], and in the East, white sweetclover occurs slightly farther north and south of yellow sweetclover [75,286,298]. In Hawaii, only white sweetclover is reported [268]. In Alaska and eastern Canada, white sweetclover occurs farther north than yellow sweetclover [37,251]. White sweetclover is also more common than yellow sweetclover in the Canadian Shield region [251]. Plants Database provides a distribution map for sweetclover. This map does not report sweetclover in Nunavut, Canada, but Turkington and others [251] indicate that white sweetclover has been collected from every Canadian province and territory.

Introduction and spread in North America: A sweetclover was reported in North America by 1664, but species was not identified [251]. Early spread of sweetclover was likely facilitated by beekeepers and agriculturalists [96]. Below is a sporadic timeline that provides information about early (pre-1920) introductions and spread of sweetclover in the United States:

- By 1739, sweetclover reported in Virginia

- In 1785, sweetclover growing in New England
- By 1814, sweetclover reported from Pennsylvania to Virginia [33]
- By 1817, white sweetclover collected by a botanist in northern Nevada and Utah [147]
- In 1856, white sweetclover cultivated in Alabama as a honey plant [10]
- On the Omaha Reservation, sweetclover first found near a Presbyterian mission built in 1857 [72]
- Since at least 1866 and 1882, white and yellow sweetclover occurred in Massachusetts, respectively [223]
- By the 1880s, sweetclover established in southern Michigan [267]
- By 1892, white sweetclover reported on Block Island, Rhode Island [7]
- In 1916, sweetclover likely introduced in Alaska during roadside revegetation [124]
- Before 1920, white sweetclover planted by Hawaiian Sugar Growers Association [268]

By the early 1900s, sweetclover was recognized and promoted for soil reclamation. Sweetclover was cultivated extensively after it was found stabilizing abandoned tobacco fields on severely eroded slopes and had improved soils enough to support tobacco agriculture again [33,219]. Even as sweetclover was being hailed as a soil-building crop, some farmers hesitated to plant sweetclover fearing it might interfere with future crop production. In a 1917 USDA publication, successful use of sweetclover in crop rotation was highlighted to provide farmers with "sufficient proof" that their fears were unfounded [33]. In Illinois, there were 48,000 acres (19,000 ha) of sweetclover growing by 1910 and 757,000 acres (310,000 ha) by 1929. In Nebraska, there were 30,000 acres (12,000 ha) of sweetclover in cultivation in 1920 and 1.1 million acres (450,000 ha) by 1930 [219]. By 1919, nearly every US state had at least 50 acres (20 ha) of sweetclover in production [33]. Cultivation was most extensive in Montana, North Dakota, Minnesota, Iowa, and Wisconsin [55].

Although first planted for bees and soil improvement, soon sweetclover was recommended for a variety of uses. Sweetclover was planted extensively for livestock and wildlife forage [5,188] and to stabilize roadside cuts [90]. During the droughts of the 1930s, sweetclover cultivation was again actively promoted, and cultivation reached peak acreages [96]. In the 1960s and 70s, yellow sweetclover was seeded on US Fish and Wildlife land to provide nesting cover for waterfowl on abandoned fields and other degraded habitats in North Dakota, South Dakota, Minnesota, and Montana [51]. Sweetclover was seeded as recently as 1996 on Forest Service land in Montana [154] and as of 1998 on a burned US military site in Utah [112].

The use of sweetclover in revegetation likely increased as studies of its success in accomplishing management goals were publicized. In western South Dakota researchers reported that perennial grass production increased by 50% within 4 years of seeding yellow sweetclover on a rangeland severely depleted by droughts and heavy grazing [172]. The abundance of sweetclover introductions has likely facilitated its spread. In Alaska, starts and stops in the distribution of sweetclover roadside populations are common, suggesting that sweetclover was introduced in multiple roadside revegetation efforts. River floodplains have likely been invaded by seed produced by sweetclover populations at road-river intersections. Once established along the river, sweetclover is likely dispersed down river during flood events [37]. Additional discussions of sweetclover dispersal and invasiveness are presented in later sections.

HABITAT TYPES AND PLANT COMMUNITIES:
Yellow and white sweetclover occupy similar nonnative habitats and are often associated with disturbances. In California [22], Nevada [117], and Florida [298], sweetclover is primarily restricted to recently disturbed sites. Although habitats described below often support both yellow and white sweetclover populations, sometimes only one is visible in a given year. See Site Characteristics for a discussion on the slightly different climate, elevation, and soil preferences and tolerances of yellow and white sweetclover.

Throughout North America, sweetclover is common in sand dune [300], prairie [10,54,193], bunchgrass [11,149,168,276], and meadow [117] habitats. Sweetclover is typically more problematic or invasive in northern than southern temperate US grasslands (review by [80]).

Sweetclover is also common in desert shrub [64], sagebrush (*Artemisia* spp.) [95,269,283], pinyon-juniper (*Pinus-Juniperus* spp.) [61], and ponderosa pine (*P. ponderosa*) [65,66,73,211] communities, but in arid regions, it may be most common in riparian areas (review by [230]).

Nearly throughout the United States, sweetclover is common in riparian areas. In much of the West and Great Plains, sweetclover occurs in riparian areas and along floodplains [239,246,293]. In the East and Great Lakes region, sweetclover riparian habitats include calcareous riverside seepage communities and fens [103,221]. Sweetclover is often dominant beneath cottonwoods (*Populus* spp.) or willows (*Salix* spp.) in North Dakota [73,269], Nebraska [42], Colorado [143,299], Arizona [6], and New Mexico [25]. Sweetclover dominance types are common at low- to mid-elevation streambanks, swales, meadows, and disturbed areas throughout Montana [89].

Less common sweetclover habitats include moderately saline marshes in Nebraska [257], disturbed subalpine fir/grouse whortleberry (*Abies lasiocarpa/Vaccinium scoparium*) forests in the northern Rocky Mountains [276], dry mixed oak and oak-hickory woodlands on the Cumberland Plateau in Tennessee [32], and hardwood hammocks in Pinellas County, Florida [69].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Melilotus alba, M. officinalis

- GENERAL BOTANICAL CHARACTERISTICS
- SEASONAL DEVELOPMENT
- REGENERATION PROCESSES
- SITE CHARACTERISTICS
- SUCCESSIONAL STATUS

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GENERAL BOTANICAL CHARACTERISTICS:

- **Botanical description**
- **Raunkiaer life form**

Botanical description: This description covers characteristics that may be relevant to fire ecology and is not meant for identification. Keys for identification are available (e.g., [82,98,101,191,235,267,268]).

Aboveground description: Yellow and white sweetclover have very similar growth habits and morphology [11,117]. In their vegetative state, yellow and white sweetclover are difficult to distinguish [98,110]. The most obvious distinction between the two species is flower color, which is yellow for yellow sweetclover and white for white sweetclover [101,107,201,268]. When flowers are dry, however, both may appear cream colored [93].

Sweetclover is a biennial [126,127,158,191], although in rare instances annual and perennial growth forms were observed. At the Matanuska Research Farm in south-central Alaska, sweetclover seed from mid-latitudes and from Alaskan roadsides produced plants that flowered in the first year. Artificial light experiments revealed that annual growth was triggered by long light periods and a lack of darkness [124,125]. In London, Ontario, some sweetclover plants clipped "rigorously" during the growing season flowered in the 3rd growing season. All plants died after flowering (Cavers unpublished data cited in [251]). Studies by Smith [217] showed that annual and biennial white sweetclover growth is controlled by a single gene, which can be altered through a single mutation.

In the 1st year of growth, sweetclover produces a single stem with many branches. Near the end of the 1st growing season, nutrients are allocated below ground to the taproot, and root crown buds are formed. In the 2nd year of growth, sweetclover stem number increases, plants are much larger, and flowers and seeds are produced (review by [220]). More details about phenology and the characteristics of 1st and 2nd year plants are provided below in the Belowground description and Seasonal development sections.

Sweetclover is generally an erect, freely branched plant up to 10 feet (3 m) tall [82,235]. Stems are coarse with alternate, 3-pinnate leaves and axillary flowers [93,158,282]. Leaflets are small, 0.4 to 1 inch (1-2.5 cm), and the pea-like, perfect flowers occur in 30- to 70-flowered racemes that measure 1.5 to 4.7 inches (4-12 cm) long [101,158,191,241]. Legumes are up to 4 mm long, scarcely dehiscent, and typically produce just 1 seed, but may produce 2 [82,98,169,191].

Although yellow and white sweetclover are more alike than different, the following morphological differences are common:

- White sweetclover is generally taller, has a more erect form, and produces coarser stems and branches than yellow sweetclover ([10], reviews by [45,220]); white sweetclover may be up to 3 feet (1 m) taller than yellow sweetclover [241].
- At peak flowering, white sweetclover racemes are much longer (8-15 times) than those of yellow sweetclover [267].
- Leaflets produced by yellow sweetclover are often twice as wide as those produced by white sweetclover [188,267].
- Yellow sweetclover legumes are wrinkled, and white sweetclover legumes are veiny [117,188].

Sweetclover growth form and morphology are variable, not only because many different cultivars, forms, and ecotypes were introduced in North America but also because growth characteristics can be influenced by environmental conditions. Plant height increases with increasing day length, and low temperatures can limit flower production (review by [251]). For descriptions of some sweetclover cultivars, see the following references: [219,273,285].

Belowground description: Sweetclover produces a taproot with secondary fibrous roots and bacterial nodules [11,101,268]. Taproots are semiwoody, and lateral roots can be extensive (reviews by [45,254]). Lateral roots may extend 6 to 8 inches (15-20 cm) from the taproot (review by [251]). In experimental fields in Columbus, Ohio, 1st-year sweetclover taproots penetrated over 4 feet (1.2 m) deep. Second-year plants had roots up to 5.5 feet (1.7 m) deep in July. Bacterial nodules occurred on roots as deep as 4 feet (1.2 m). Increased root length between these 1st- and 2nd-year plants may not reflect plant age but site differences. Most sweetclover plants attained their maximum root length in the 1st year. Root systems were shallower in dry than moist soils [289].

Bare [10] reports that yellow sweetclover roots are generally shorter but spread farther than white sweetclover roots. First-year white sweetclover dug from a field in Columbus, Ohio, in early May produced taproots that averaged 9.3 inches (23.6 cm) long and 0.3 inches (0.8 cm) in diameter [289]. On a sandy site near Central City, Nebraska, researchers described the root system of a 1st-year white sweetclover plant that was 3 feet (1 m) tall with 15 stems. Near the root crown, the taproot measured 1.5 inches (4 cm) in diameter. Diameter tapered to about 1 cm by about 1.5 feet (0.5 m) deep and remained that size to the maximum taproot depth of 5 feet (1.5 m). Most lateral roots also reached 5 feet (1.5 m) deep, but rarely did they extend more than 2 feet (0.6 m) from the taproot. Sublateral roots were abundant, and generally the soil up to 5 feet (1.5 m) deep beneath white sweetclover was "well filled with roots" [275].

Raunkiaer [194] life form:
Hemicryptophyte
Therophyte

SEASONAL DEVELOPMENT:
Sweetclover flowers April to October throughout North America [11,52,82,117,158,191,235,241,292]. Generally yellow sweetclover flowers 1 to 3 weeks earlier than white sweetclover [39,55,220,229,254,267,289]. The flowering rate in individual white sweetclover racemes is usually about twice as fast as that for yellow sweetclover [251], which may explain why Willard [289] suggests that yellow sweetclover flowering is more uniform than that of white sweetclover. Moisture conditions, elevation, and likely other site factors can affect flowering. Following a dry spring and an especially dry June in Ohio, sweetclover flowered for a second time in mid- to late July. There were several moderate rains in July [289]. In ponderosa pine forests in north-central Arizona, the flowering period for yellow sweetclover was much shorter at a site that was 600 feet (180 m) higher than its comparison site [31].

Sweetclover green-up, fruit development, and seed maturation were described in a few locations. In north-central Arizona, vegetative growth of yellow sweetclover began in mid-April. Vegetative growth was delayed 2 to 3 weeks at a high-elevation site compared to a low-elevation site. Mature yellow sweetclover fruits were present by late August at the low-elevation site, and fruit maturation continued into November at the high-elevation site [31]. In southern Ontario, there were usually ripe yellow sweetclover seeds by late July, but it was early August before ripe white sweetclover seeds occurred. Often sweetclover seeds remained on the plant through the winter (Rempel unpublished data cited in [251]).

Root crown buds and carbohydrate storage: In late summer and early fall, 1st-year sweetclover plants increase their taproot size, root crown bud number and size, and underground carbohydrate storage. In fields near Ames, Iowa, stems are 90% or more of the total weight of 2- to 3-month-old white sweetclover. By late September of the 1st growing season, roots provide up to 80% of total plant weight [157]. In fields in Wisconsin, the largest increases in root size and carbohydrate storage for 1st-year sweetclover occurred between 18 September and 18 October [216]. Additional field studies conducted in Ames, Iowa showed that 1st-year sweetclover taproot weight and root crown bud abundance increased from late summer to early fall. When particularly "vigorous" 1st-year yellow sweetclover plants were excavated on 20 August, taproots averaged 2.6 g, and there were 2.2 root crown buds/plant. Taproot weight averaged 11.7 g, and there were 29.4 crown buds/plant on 20 November. Greenhouse experiments revealed that increases in taproot size and root crown bud production occurred with decreasing photoperiod [118]. In experimental fields in Columbus, Ohio, sweetclover produced large root crown buds in August. Buds became larger and more numerous until November [289]. At the Agronomy Research Center in West Lafayette, Indiana, researchers found that total nonstructural root carbohydrates (TNCs) for 1st-year yellow sweetclover were highest from November to December. TNCs were lowest in May after the emergence of 2nd-year plants [142]. For more on how these changes in root development and storage may affect management of sweetclover, see Control.

REGENERATION PROCESSES:
Sweetclover reproduces from seed. Cases of vegetative sprouting after damage have been reported, but are rare (see Vegetative regeneration for more information).

Pollination and breeding system: Sweetclover flowers are perfect [55,158], and although experiments have shown that seed can be produced by self-fertilized flowers, this rarely occurs in natural conditions [34], especially for yellow sweetclover [122]. Sweetclover flower structure encourages cross pollination by insects. When insects land on lower flower petals, stigma and anthers bend and contact the insect body [10]. Bees are the most common sweetclover pollinators; honey bees, bumble bees, and leaf-cutter bees were reported as important pollinators ([144,285], review by

[55]). Successful pollination by insects can be affected by season and weather. Cloudy, wet weather decreases bee activity [10,285], and Bare [10] reports that the honey production capacity of sweetclover is greater in early summer than late summer and greater for areas west of the Mississippi River than areas east of the River.

Fertilization: After reviewing published studies and conducting original studies on many yellow and white sweetclover strains and varieties, Kirk and Stevenson [122] concluded that self fertilization does occur naturally for some white sweetclover strains or varieties, but seed production from naturally self-fertilized yellow sweetclover is rare. Studies that followed the Kirk and Stevenson review (published in 1931) generally support their conclusions. In the greenhouse, researchers used genetic markers to determine that cross-fertilization in annual and biennial white sweetclover populations averaged 67% and 58%, respectively [79]. When yellow sweetclover flowers were artificially self pollinated, fruit set ranged from 0 to 69.2% and averaged 19.3% [206]. In a field experiment along the Rio Grande in Albuquerque, New Mexico, fruit set was low when yellow sweetclover racemes were protected from insect visitors. Fruit set by protected racemes (6%) was significantly (P<0.001) lower than that set by unprotected racemes (44%) [163]. For more on this study, see the Seed production section below.

Seed production: High levels of seed production are reported for sweetclover ([228], Rempel and Cavers unpublished data cited in [251]), and available reports indicate that white sweetclover generally produces more seed than yellow sweetclover (Rempel and Cavers unpublished data cited in [251]). However, seed production estimates using calculations that assume all flowers produce fruits and all fruits produce 1 seed can largely overestimate production [126]. Methods used to determine seed production in the following studies were not reported. In London, Ontario, large white sweetclover growing in open conditions produced 200,000 to 350,000 seeds/plant. Large yellow sweetclover growing under similar conditions rarely produced more than 100,000 seeds/plant (Rempel and Cavers unpublished data cited in [251]). In North Dakota, an average-sized white sweetclover with 5 stems produced 14,235 seeds [228].

Klemow [126] found that estimates of seed production were exaggerated when estimation calculations did not factor in flower abortion and empty fruits. In a white sweetclover population ecology study in an abandoned rock quarry in Syracuse, New York, Klemow [126,127] estimated that white sweetclover produced an average of 4,380 fruits/plant and 11,640 fruits/plant in sparsely vegetated (cover 8%) and densely vegetated (cover 41%) sites, respectively. About 80% of fruits contained a seed, so the average seed production per plant was 3,530 on the sparse site and 9,710 on the dense site. Fruit and seed production estimates, however, assumed that all flower buds counted in August would develop into flowers, form fruits, and produce seed. A later visit to these sites showed that flower buds were often aborted or failed to produce fruit. When abortion and empty fruits were factored into calculations, the most and least seed produced by white sweetclover over the 5-year study period was 5,000 and 171 seeds/plant, respectively [126,127].

Sweetclover seed production is often reduced if plants are damaged, grow on infertile sites, or if insect visitation is limited by weather, insectivorous birds, or other means. In Ontario, Canada, researchers observed that damaged sweetclover plants or plants in extremely infertile soils sometimes produced less than 100 seeds (Rempel and Cavers unpublished data cited in [251]). After many field observations and studies, Coe and Martin [34] found that seed production was greater in dense than in sparse sweetclover stands, reduced in drought conditions, and lower when cloudy, rainy weather limited insect visitation. In Arlington, Virginia, a 3-foot (0.9 m)-tall sweetclover produced 196 racemes, and racemes produced an average of 20.4 fruits each. This plant grew in a stand density of 4 sweetclover/ft^2. When plants were protected from insects, racemes averaged 0.63 fruits each [34]. Along the Rio Grande in Albuquerque, New Mexico, yellow sweetclover fruit set increased with increasing distance from cliff swallow colonies. When plants were within 660 feet (200 m) of the colonies, fruit set was reduced by about half. Once cliff swallow chicks fledged, however, the relationship between fruit set and colony proximity was lost. Cliff swallows were consuming insects that visited yellow sweetclover. Researchers estimated that a cliff swallow colony of 150 nests could consume over 500,000 insects per day, based on an average insect size of 5 mm [163].

Seed dispersal: Because sweetclover lacks appendages for wind dispersal, most seed falls near the parent plant (review by [49]), but observations and experiments indicate that long-distance dispersal by animals and water is possible. Long-distance dispersal may also occur through the transport of contaminated seed or animal feed ([14], review by [49]).

Water: Several sources suggest that sweetclover seed is dispersed by water. Based on plant distributions along waterways in Alaska [37,225], Montana [14], Arizona [237], and New Jersey [221], sweetclover seed dispersal by water seems likely. Experiments conducted in London, Ontario, showed that over 65% of white sweetclover seeds were still floating after 15 minutes in violently agitated water (unpublished experiments described in [251]).

Animal: Observations and experiments leave little doubt that sweetclover seed is transported by animals. In the Intermountain West, sweetclover spread along cattle trails was reported [11], and in the Missouri Ozarks, sweetclover was restricted to horse trails [236]. While collecting sweetclover seeds for later experiments, students found that sweetclover seeds with fruit layers attached were transported on human clothing (unpublished experiments described in [251]).

Experiments show that viable sweetclover seed can be recovered from animal feces. When white-tailed deer pellets were collected from mixed-deciduous forests in Ithaca, New York, a maximum of 13 white sweetclover seeds germinated/pellet group [171]. Three white sweetclover seeds were collected from crops of mourning doves, and 1 seed germinated. A seed recovered from the gizzard did not germinate [8]. When calves, horses, sheep, hogs, and chickens were fed a known quantity of white sweetclover seed, 17.7%, 10%, 17.1%, 11%, and 0% of the seed germinated from collected feces, respectively. When recovered seeds were treated with sulfuric acid, germination rates increased by 40% or more, indicating that a large portion of white sweetclover seeds were still hard after passing through these animals (see Germination for more about hard sweetclover seed). Five percent of white sweetclover seeds that remained inside calves for up to 48 hours germinated. Ten percent of seeds recovered after 48 to 80 hours inside calves germinated. Sweetclover seeds may also be transported in partially composted manure. Two percent of white sweetclover seeds germinated after 2 months of burial in manure [92].

Although wind dispersal is relatively unimportant for sweetclover, a study found that the weight of white sweetclover seeds depended on time of production. Fifty seeds produced early in the growing season and late in the growing season averaged 78.9 mg and 59.3 mg, respectively [28]. Whether or not lighter seeds could be dispersed longer distances is unknown, and germination percentages were not reported.

Seed banking: Studies clearly indicate that sweetclover produces a seed bank; however, estimates of the longevity of seed in the soil vary from >2.5 [126,260] to 81 years (review by [204]). Sweetclover seeds have germinated after 81 years of storage (Becquerel 1934 cited in [41]), but field studies involving the recovery and germination of buried seed over time are lacking.

Sweetclover produces a percentage of hard seeds (see Germination) that germinate only after scarification. Hard seeds likely make up the majority of the seed bank [115,233]. When white sweetclover seed was buried in pots on an abandoned rock quarry near Syracuse, New York, 43% and 26% of the seed on sparsely and densely vegetated sites, respectively, failed to germinate but was still viable a year later [126]. In other studies, sweetclover emerged from soil samples although plants were absent from the aboveground community [29,198].

Storage conditions: Sweetclover seeds have survived and germinated after decades in storage, but storage conditions were rarely described, making it difficult to assess their relevance to field situations (Becquerel 1934 cited in [41], Ewart 1908 cited in [274], Munn 1954 cited in [219], Crocker 1938 cited in [251]). Thirty percent of white sweetclover seeds germinated after 19 years in an unheated shed in Twin Falls, Idaho. Maximum and minimum temperatures for Twin Falls can be 105 °F (41 °C) and -26 °F (-32 °C), and in the shed, temperatures were slightly higher [106]. After 81 years of storage in unknown conditions, 0.6% of white sweetclover seed was viable (Crocker 1938 cited in [251]).

Field conditions: Field studies suggest that sweetclover seed remains viable after 14 to 17 years in the soil but may survive over 50 years in the soil. Several researchers indicate that sweetclover can be abundant even after "several years" without mature plants on a site ([115], review by [187]). After 5 years of underwater storage in Prosser, Washington, a small proportion of white sweetclover seed germinated, but 42% of seeds were still firm [36]. In North Dakota, sweetclover remained viable in the soil for at least 14 years. Sweetclover was planted and allowed to produce seed on 2 agricultural plots. In the following years, plots were cultivated and planted to other crops. Sweetclover seedlings emerged almost every spring for 14 years, even though 1st-year plants were killed each year [233]. On experimental plots at the University of Saskatchewan, white sweetclover seed survived 17 years in the soil. Crop history records and the distribution and quantity of seed led the researcher to conclude that white sweetclover germinated from soil-stored seed, not dispersed seed [13]. In another field study, a researcher visited several areas where circumstances would indicate long-lived, soil-stored seed. In Copenhagen, Denmark, a pork market that was built in 1910 was torn down in 1961. Some archaeological digging occurred, and by 1963, yellow sweetclover was growing on site. Because wind-dispersal is unlikely, the researcher speculated that yellow sweetclover germinated from soil-stored seed [176].

Germination: Sweetclover generally produces both readily germinable and water-impermeable or "hard" seeds. Percentages of hard seed produced vary. Of the sweetclover seeds collected from the Royal Botanic Gardens in Cambridge, England, 32% of yellow sweetclover and 85% of white sweetclover seeds were hard [274]. Over 90% of white sweetclover seeds collected in July and August from roads and grasslands near Leuven, Belgium, were hard [260]. The seed collected from sweetclover that had germinated from seed stored in the soil for up to 14 years in North Dakota was nearly 100% hard [233]. Factors controlling the proportion of hard seed produced were not described in the available literature (2010).

Germination of hard sweetclover seeds can be encouraged by heat treatments and fluctuating temperatures around freezing. Light is not required for sweetclover germination, and high temperatures (95 °F (35 °C)) discourage germination [248]. One study found that germination of white sweetclover seeds was significantly lower (P=0.0069) in the field (6.7%) than in the laboratory (11.8%) [181], suggesting that germination results from greenhouse studies may not be fully realized in field conditions.

Heat: Researchers report that fire can stimulate germination of soil-stored sweetclover seed ([35,128], review by [45]). In the laboratory, heat treatments have increased the germination of hard sweetclover seed. After soaking hard white sweetclover seeds in 180 °F (80 °C) water, most became permeable to water (Martin 1922 cited in [190]). Dry heat treatments of 150 °F (66 °C) for 5 days produced a maximum germination increase of 10% for hard sweetclover seed. One minute at 220 °F (100 °C) produced only a 2.5% increase in hard seed germination, but 4 minutes at 220 °F (100 °) significantly (P<0.05) increased the germination of hard seeds, by 9.1% [200]. For more information on sweetclover and fire, see Fire Effects and Management.

Chilling: Alternating temperatures that include near freezing temperatures may increase germination of hard sweetclover seed more than constant freezing or chilling temperatures [155,260]. After conducting several experiments, Martin [155] found that moisture content did not affect softening or germination of hard seed but that 2 or more months of alternating temperatures around freezing produced high germination percentages. Seeds buried outdoors from October to late April at 1 to 3 inches (2.5-7.5 cm) deep germinated better than seeds buried deeper, where minmum temperatures and temperature fluctuations were reduced [155]. After conducting field and laboratory experiments on white sweetclover seed collected in Leuven, Belgium, researchers concluded that chilling and exposure to alternating temperatures increased germination [260]. Fluctuating cold temperatures may not be sufficient for germination of all hard sweetclover seed, however. In experimental field plots at the University of Saskatchewan, nearly all white sweetclover seeds required scarification to germinate even after 17 years in the soil [13].

Other vegetation: Presence of other vegetation may affect sweetclover germination. In northern Arizona, yellow sweetclover formed dense stands on sites lacking bunchgrass cover, but as bunchgrasses increased yellow sweetclover decreased. Experiments revealed that live foliage extracts from Arizona fescue (*Festuca arizonica*) and mountain muhly (*Muhlenbergia montana*) significantly reduced the germination percentage, germination rate, and initial root development of yellow sweetclover (P<0.05 for germination percentage and rate) [199].

Seedling establishment and plant growth: Sweetclover seedling establishment and growth are generally best in moist and moderated conditions. Several studies indicate that sweetclover utilizes other vegetation as nurse plants for successful establishment. Yellow sweetclover seedlings are considered more "vigorous" than white sweetclover seedlings (review by [220]), but reasons for this claim were not provided.

Emergence timing: Although sweetclover seedlings can emerge throughout the growing season, emergence peaks in the spring ([126,127], review by [251]). In southern Ontario, sweetclover seedlings emerge throughout the year, but emergence is greatest in March and April. Another smaller peak in emergence occurs in September or October. With 3 or more days above freezing, winter emergence can occur. Survival rates are best for seedlings emerging from late March to early May. Early emergence can compress the sweetclover life cycle into one year: Sweetclover seedlings that emerged in February or March on the gravel bars of the Thames River typically flowered in their first year (review by [251]).

Burial and moisture: Moisture is important for initial sweetclover establishment (125,124, review by [251]), and planting guides suggest seeding sweetclover 0.5 inch (1.3 cm) deep in "heavy soils with good moisture", and 1 inch (2.5 cm) or deeper in "light soils" or low-moisture conditions (review by [219]). Experiments conducted on white sweetclover seed collected from China's Qubqi Desert also indicate that deeper burial may improve survival of seedlings in low-moisture conditions. Generally, establishment in sand was better from seeds buried more deeply (1.2 inches (30 mm) under a low-moisture regime and more shallowly 0.2 inch (5 mm) under a high-moisture regime. Seeds buried 2 inches (5 cm) deep generally failed to establish. Because light is not required for germination, researchers speculated that anoxic conditions at this depth may explain poor establishment. In a companion experiment, researchers found that white sweetclover seeds submerged for 6 days produced radicles that were deformed or missing growing tips [248].

Site conditions: Observations indicate that sweetclover seedling density, arrangement, and survival vary with site conditions. High seedling densities are common in riparian areas. Along the Nenana River floodplain in Alaska, white sweetclover seedling density ranged from 407 to 1,307 seedlings/2 m^2 plot. Within the plots, seedlings were highly clumped. There were often more than 60 white sweetclover seedlings/400 cm^2 [225]. Following winter flooding on the dry surface zone of the Hassayampa River in central Arizona, sweetclover seedling establishment was high. Establishment timing and high sweetclover seedling cover prevented establishment of saltcedar (*Tamarix* spp.) in the area [237].

In Ontario, sweetclover seedling density and survival varied by soil type. On fertile clay or loam soils, sweetclover seedlings were typically clumped and the majority did not survive. In the greenhouse, more than 75% of sweetclover seedlings died within 5 months when they occurred at a density of 600 seedlings/m^2. On gravelly, sandy, or stony soils, sweetclover seedling mortality was high; fewer than 5% of seedlings survived more than 4 months. On steep eroded banks and frequently disturbed sites, sweetclover seedling emergence was low but subsequent mortality was also low, so that these inhospitable sites generally supported a few large plants that typically produced abundant flowers (review by [251]).

Disturbances and neighboring vegetation: Sweetclover is often associated with disturbed, open sites, but some studies show that sweetclover establishment may be improved when other vegetation is present. Sweetclover seedling survival increased with gap size in a Kentucky bluegrass (*Poa pratensis*)-dominated old field in southwestern Michigan. Although sweetclover germination was high in the 0.5, 1, 2, and 3 cm diameter gaps cut into the sod, early seedling survival was significantly lower in small gaps than in large gaps ($P<0.01$). Of the 96 seeds planted in each gap size, there were 30 seedlings in 0.5 cm and 56 to 58 seedlings in the 2 and 3 cm gaps 30 days after seeding [26]. In a smooth brome-dominated old field in Regina, Saskatchewan, yellow sweetclover seedlings were significantly ($P<0.05$) smaller in plots where belowground biomass was removed than in plots where it was left intact [70]. Other research indicates that disturbance does not favor sweetclover establishment. In mountain grasslands in central Argentina, white sweetclover seedling establishment was more likely on undisturbed than disturbed sites. Fewer white sweetclover seedlings emerged on sites where all above- and belowground vegetation was removed than on undisturbed sites [181].

Neighboring vegetation may act as a nurse crop by moderating establishment conditions for sweetclover seedlings. During field experiments conducted at the tallgrass Konza Prairie Biological Station in northeastern Kansas, yellow sweetclover seedling establishment increased with increased density of dominant C4 grasses. Yellow sweetclover was seeded into plots where species richness was reduced to varying degrees. As the abundance of dominant grasses decreased, the establishment of yellow sweetclover seedlings decreased significantly ($P=0.01$). The study area burned several weeks before this field experiment, so light levels were high in all intact plots. Researchers suggested that species removal may have lead to the loss of safe sites and made conditions too harsh for successful establishment [218]. In an abandoned rock quarry in Syracuse, New York, there were up to 15.5 white sweetclover seedlings/0.25 m^2 on a sparsely vegetated site and 116 white sweetclover seedlings/0.25 m^2 on a densely vegetated site. Water-holding capacity was greater on the dense than the sparse site. In a year that was very warm and dry during the initial seedling establishment stage, the presence of vegetation seemed to improve survival of white sweetclover seedlings. However, when 5 years of data were pooled, survival of white sweetclover was not significantly different between densely and sparsely vegetated sites. Establishment and survival of white sweetclover on these sites in a normal and a dry year are shown in the table below [126,127].

Establishment and survival of white sweetclover in a normal (1976) and a dry (1977) year on sparsely (8% cover) and densely (41% cover) vegetated sites [126,127]

White sweetclover attribute measured	Sparse vegetation		Dense vegetation	
	1976 (normal)	1977 (dry)	1976 (normal)	1977 (dry)
Established seedlings (<3 cm tall) (number/0.25 m^2)	33.9	0.44	32.2	11.1
Surviving to fall (%)	16.0	0	10.6	1.54
Surviving the winter (%)	5.8	0	5.1	0.7
Flowering in 2nd year (%)	3.4	0	3.3	0.7

Vegetative regeneration: Vegetative regeneration in sweetclover is rare and limited to damaged plants [289]. Sprouting may occur if sweetclover is damaged before producing flower buds (review by [45]) or once large crown buds are formed on 1st-year plants. However, a review by Soleki [222] reports that if sweetclover is cut close to the ground before or in early stages of flowering, sprouting is unlikely. In the 1st year after a spring prescribed fire in east-central Minnesota, yellow sweetclover "sprouted vigorously" [182]. Although the phenology of yellow sweetclover at the time of the fire was not described, it is likely that many plants had not flowered (based on flowering dates reported for North Dakota [229]). In fields in Columbus, Ohio, sweetclover was "nearly impossible" to kill after large sweetclover crown buds were produced (August-November). Sweetclover grew even after fields were plowed as early as 28 August [289].

SITE CHARACTERISTICS:
Throughout its nonnative range, sweetclover is described on open, disturbed sites that include roadsides, railways, fields, and waterways [10,37,48,98,151,188].

Climate: The wide distribution of sweetclover implies wide climatic tolerance. Moisture is important for sweetclover seedling establishment, but once established, plants tolerate extremely dry conditions. In the fall, contractile roots pull sweetclover root crowns beneath the soil surface (=2 inches (5 cm)), protecting plants from freezing temperatures (review by [251]). Yellow sweetclover is considered more heat and drought tolerant than white sweetclover (reviews by [220,254]). Although yellow sweetclover has also been described as more cold hardy than white sweetclover (review by [254]), current distributions suggest this may not be true (see General Distribution). In Alaska, sweetclover occupies habitats with extreme weather. In Ketchikan, annual precipitation averages 160 inches (3,940 mm) and temperatures average 45 °F (7.2 °C). In interior Alaska, annual precipitation can be as low as 6 inches (170 mm), and the average annual temperature can be as low as 26 °F (-3.3 °C) [37]. During growth chamber experiments, researchers found that 1- to 4-week-old yellow sweetclover seedling survival was high at 21 °F (-6 °C). Survival was much lower at 18 °F (-8 °C) [165].

Elevation: Range of elevations reported for sweetclover in western North America	
Area	Elevation
Arizona (Grand Canyon)	1,600 to 8,500 feet (488-2,591 m); yellow sweetclover occurs about 330 feet (100 m) above and below white sweetclover [227]
California	Below 4,920 feet (1,500 m) [98]
Colorado	Yellow sweetclover: 4,000 to 7,500 feet (1,220-2,290 m); white sweetclover: 4,500 to 7,500 feet (1,370-2,290 m) [93]
Hawaii	White sweetclover: 15 to 4,400 feet (5-1,340 m) [268]
Nevada	Yellow sweetclover: 2,300 to 6,300 feet (700-1,900 m); white sweetclover 1,200 to 6,500 feet (370-1,980 m) [117]
New Mexico	4,000 to 8,000 feet (1,200-2,400 m) [158]
Utah	Yellow sweetclover 4,000 to 8,010 feet (1,220-2,440 m); white sweetclover 3,490 to 7,000 feet (1,065-2,135 m) [282]
British Columbia (southeast)	Good growth from 5,910 to 7,320 feet (1,800-2,230 m); poor growth above 7,970 feet (2,430 m) [233]

Soils: Sweetclover grows on a variety of alkaline or slightly acidic soils ([33,37], review by [220]). Very low nutrient levels and fine- and coarse-textured soils are tolerated ([37,167,245,279], review by [233]). Several reviews indicate that yellow sweetclover tolerates nutrient-poor and dry soils better than white sweetclover [49,89,219,254].

Sweetclover occupies a variety of soil types and textures but growth and productivity can vary by soil type and region. Residents of Fort Smith near Canada's Wood Buffalo National Park reported that sweetclover expanded its range on fine-textured soils but nevertheless was primarily restricted to disturbed sites [279]. In meadows in Michigan's Oakland County, white sweetclover was "plentiful" on sites with "considerable clay" [245]. In southwestern North Dakota, yellow sweetclover occupied a variety of habitats with textural classes ranging from loams to clays and pH ranging from 7.9 to 8.8 [73]. A review reports that sweetclover is most productive on silt loams to clay loams with neutral to alkaline pH [89]. Wasser [273] reports a minimum pH tolerance of 5.5 for yellow sweetclover. Seeding of yellow sweetclover was successful on a South Dakota rangeland where soils were up to 65% clay [172]. On riverbanks in Quebec, white sweetclover was most common on alkaline, sandy soils with very rapid drainage and low to high degrees of stoniness [167]. On Alaska rivers and roads, white sweetclover density was lower on cobbly than on sandy surfaces [37].

Many studies report an association between white sweetclover and calcareous soils. White sweetclover was especially common on calcareous soils in Michigan [267], the northeastern United States and southeastern Canada [75], the Gulf and Atlantic Coasts [52], and eastern Texas [272]. During a study conducted in Canada, researchers found that white sweetclover plants grown from seeds collected on calcareous soils grew well only on calcareous soils. White sweetclover plants grown from seed collected on acidic soils grew well on acidic and calcareous soils but grew best on calcareous soils [192].

Salinity: Sweetclover tolerates moderate salinity [119,257]. A review reports that salinity levels of 0.2 to 0.4% or 2 to 4 ppt (3-5 mS/cm) are tolerated (review by [233]). In Alberta, Saskatchewan, and Manitoba, white sweetclover occurred on soils where salt crystals were visible on the surface [17,50]. Yellow sweetclover was reported in a marsh near Lincoln, Nebraska, where the salinity averaged 0.2% [257]; white sweetclover grew along the South River in Anne Arundel County, Maryland, where salinity levels ranged from 0.2 to 3.6% [185].

Moisture and flooding: Sweetclover is common in riparian areas and typically tolerates short-duration flooding early in the growing season [11,238]. A review indicates that white sweetclover is slightly more flood tolerant than yellow sweetclover. In southern Ontario, white sweetclover is occasional along rivers with several weeks of winter and spring flooding (review by [251]). Along Alaska's Nenana River, white sweetclover survived shallow flooding that lasted only a few days [37]. In southern Idaho, Rosentreter [202] reported that yellow and white sweetclover abundance increased in periodically flooded stream banks, but yellow sweetclover is typically killed by high water during the growing season (review by [89]). During field experiments in London, Ontario, fewer than 10% of sweetclover plants survived 5 days of immersion in the Thames River when the temperature was 68 °F (20 °C) (Weekes and Cavers unpublished data cited in [251]).

SUCCESSIONAL STATUS:
Generally sweetclover is an early to mid-seral species common on open, disturbed sites. Sweetclover rarely persists in dense shade and often appears early in the succession of recently disturbed or bare sites. It is important to note that year-to-year sweetclover cover can vary a lot; "boom" growth years are common [262]. In South Dakota, times when areas are covered with white and/or yellow sweetclover flowers are described as "sweetclover years" [115]. In big sagebrush/grasslands in central Montana, researchers reported 10% to 12% cover of yellow sweetclover in one year and less than 1% cover the next [270]. Large fluctuations in sweetclover cover make interpretation of seral change along a chronosequence difficult.

Shade: Most reviews and studies indicate that sweetclover grows best in full sun or partial shade. A review of Upper Midwest habitats indicates that sweetclover is most frequent in open, disturbed upland prairies, savannas, and dunes (review by [45]). Other reviews report that sweetclover is less "vigorous" and produces fewer seeds in shade than in full sun [251]; however, shade tolerance may be greater in hot, dry climates [222].

Most studies and observations indicate that although sweetclover is common on open sites, some degree of shade tolerance also exists. At the Mammoth campground in Yellowstone National Park, yellow sweetclover was positively associated with open canopy conditions ($P<0.02$), and 75% of yellow sweetclover occurrences were beneath canopies of 10% or less [1]. In the Swan Valley of northwestern Montana, yellow sweetclover cover was much greater on logged (14%) than unlogged (<1%) coniferous forests. Logging occurred up to 30 years earlier [67]. Along rivers in Alaska, white sweetclover did not occur beneath dense alder (*Alnus* spp.) or balsam poplar (*Populus balsamifera*) canopies [37]. In quaking aspen (*P. tremuloides*) woodlands that dominated about 90 years after deforestation of the boreal mixed-wood forest in Alberta, white sweetclover was restricted to within 49 feet (15 m) of the deforested edge [71]. Some studies indicate mild to substantial shade tolerance in sweetclovers. In a savanna in the University of Wisconsin-Madison Arboretum, white sweetclover cover was 7.5% beneath oak (*Quercus* spp.) canopies and 6.7% outside of the canopies. Photosynthetically active radiation was 52% to 83% lower beneath than outside oak canopies [131]. Along portions of the Rio Grande in New Mexico, sweetclover often dominated beneath a dense overstory of Fremont cottonwood (*P. fremontii*), Goodding willow (*Salix gooddingii*), and Russian-olive (*Elaeagnus angustifolia*). In these habitat types, litter was 1 to 6 inches (2.5-20 cm) deep [25], suggesting that sweetclover seedlings as well as mature plants were tolerating heavy shade.

Bare site succession: Bare soil is rapidly colonized by sweetclover, but rarely does sweetclover persist as a dominant. On calcareous soils deposited during construction in central Germany, white sweetclover dominated (60-75% cover) in the 2nd and 4th years of succession. White sweetclover populations collapsed in the 5th year, but in the 7th and 10th years of succession, white sweetclover cover exceeded 10% [208]. In Plzen, Czech Republic, white sweetclover dominated a nutrient-poor site 6 years after bare soil was left by a human-caused disturbance. White sweetclover did not dominate in any other year [189]. Yellow sweetclover production was greatest 4 years after disturbance in a sagebrush habitat in northwestern Colorado. After all vegetation and the top 2 inches (5 cm) of soil were removed and the remaining 14 inches (35 cm) of soil was mixed, yellow sweetclover production was 1 g/m^2 in first postdisturbance year, 13 g/m^2 in the 2nd, 5 g/m^2 in the 3rd, 32 g/m^2 in the 4th, and less than 1 g/m^2 in the 5th, 6th, and 7th years [161]. Near Duluth, Minnesota, yellow sweetclover appeared 4 years after bare sand was deposited in a high-water year. Persistence beyond this time was not reported [136]. On fly-ash mine pits in Tennessee, the importance of white sweetclover was greatest on 8-year-old pits when 6-month, 3-year, and 8-year-old pits were compared. Fly ash that is deposited into the pits is "essentially sterile", free of seeds and other reproductive plant material [76]. Sweetclover occurred in the early succession of sand flats in eastern New York created by deposition of material dredged from the Hudson Estuary channel. Dredging began in 1929, and species composition was first evaluated in 1935 [162]. In vacant lots in Montreal, Quebec, white sweetclover-dominated sites had a large amount (10.8-26.5%) of bare ground [265].

Floodplain succession: On floodplains, sweetclover is common in early- and mid-seral stages of succession. In southwestern North Dakota, yellow sweetclover occurs in early-seral eastern cottonwood-Rocky Mountain juniper (*P. deltoides-Juniperus scopulorum*) stands, and mid-seral eastern cottonwood-green ash (*Fraxinus pennsylvanica*) stands on more stable floodplains [73]. In eastern cottonwood stands along the Missouri River in southeastern South Dakota, white sweetclover cover generally decreased with increasing eastern cottonwood stand age. In stands estimated to be 10, 14, 23, 35, and 55 years old, yellow sweetclover cover averaged 8%, 12%, 2%, 2%, and 0%, respectively [291].

Old field succession: Abandoned agricultural fields are common sweetclover habitat. Typically sweetclover abundance is lowest in the most successionally advanced old fields. Likely the composition and density of associated vegetation affects sweetclover persistence. In the Black Forest of central Colorado, yellow sweetclover occurred on a 4-year-old field but not on 1-, 9-, or 22-year-old fields [145]. When a previously cultivated site at the Fermi National Accelerator Laboratory in Illinois was seeded with native tallgrass prairie species, white sweetclover frequency was greater after 1 to 6 years after seeding than 12 years after seeding [215]. At the WW Kellogg Biological Station in Kalamazoo County, Michigan, large white sweetclover patches occurred in fields last plowed 10 to 16 years previously [284]. When different-aged stands were sampled along a chronosequence of old field to deciduous forest in southwestern Ohio, sweetclover was present but not common on 2-, 10-, and 50-year-old fields. Sweetclover did not occur in stands 90 or 200 years old. Two-year-old fields were dominated by red clover (*Trifolium pratense*); 10-year-old stands were dominated by Canada goldenrod (*Solidago canadensis*) and meadow fescue (*Schedonorus pratensis*); 50-year-old stands were dominated by Canada goldenrod and had 30% cover of white ash (*F. americana*) and black cherry (*Prunus serotina*). Stands 90 years and older were dominated by deciduous forest species [264].

Disturbances: Throughout its nonnative range, sweetclover is described on disturbed sites [10,89,201,267,282,298]. Generally sweetclover occurs on recently disturbed sites, but without further disturbance, sweetclover fades from the community. In mixed- and shortgrass prairie near Cheyenne, Wyoming, yellow sweetclover occurred and was sometimes frequent on sites disturbed about 3 to 25 years earlier. On undisturbed sites or sites disturbed more than 25 years ago, yellow sweetclover was rare or absent [205].

In prairies, sweetclover often occurs on soil mounds created by wildlife. In the prairie potholes of Montana, North Dakota, South Dakota, and western Minnesota, sweetclover occurred on earth mounds created by pocket gophers and badgers [99]. In Billings, North Dakota, yellow sweetclover occurred in all 4 active prairie dog towns visited [234]. On Cayler Prairie Preserve in Dickinson County, Iowa, sweetclover was consistently associated with excavation mounds created by badgers that were hunting ground squirrels. Sweetclover was uncommon in undisturbed tallgrass prairie [186]. In Wisconsin prairies, soil mounds created by ants or other animals are the first establishment site for white sweetclover [43].

Roads and waterways are common sweetclover habitats and have been important to sweetclover spread (see Introduction and spread). In Alaska, sweetclover was restricted to roadsides and floodplains and did not occur in roadless areas [37]. In the Northern Rocky Mountains, yellow sweetclover occurred in disturbed areas (roads, ditch banks, or logged sites) above and below timberline but did not occur in little-disturbed or undisturbed vegetation [276]. In mixed-grass prairie and open ponderosa pine woodlands in Wind Cave National Park, South Dakota, logistical regression analyses revealed that sweetclover was associated with roads and trails. Yellow sweetclover was also common in prairie dog towns, and white sweetclover was most common on low-elevation, recently burned sites [177]. In the wet to mesic Chiwaukee tallgrass prairie in Wisconsin, density of white sweetclover was significantly greater on past disturbed than undisturbed transects [164]. In the late 1990s, researchers surveyed 1,940 miles (3,120 km) of county and state roads in western Adirondack Park, New York. White sweetclover occurred at more than 100 sites in the survey area [20].

Grazing: In the studies that evaluated sweetclover on grazed and ungrazed sites, typically cover on grazed sites was similar to or greater than cover on ungrazed sites. Yellow sweetclover persisted on grazed and ungrazed sites during drought conditions in semiarid grassland in north-central Arizona. Moderate- and high-impact, short-duration grazing rotations were evaluated. During the 8-year study, precipitation levels for the 8 months prior to July were 2.5 to 12 inches (62.4-312.8 mm) lower than the 20-year average [146]. In western Colorado, yellow sweetclover cover within long-term (41-51 years) ungulate exclosures in sagebrush and mountain shrubland did not differ much from cover outside the exclosures [153]. When grazed and ungrazed portions of Fults Prairie, Illinois, were compared, yellow sweetclover was absent from the ungrazed portion and had 36% frequency on the grazed portion. Researchers suggested that decreased abundance of climax vegetation on grazed sites increased the success of yellow sweetclover and other “weedy” species [174]. While aboveground cover of yellow sweetclover may not differ on grazed and ungrazed sites, seed density differed in soils collected from grazed and ungrazed mixed-grass prairie sites in western North Dakota. Fewer than 5 yellow sweetclover seedlings emerged from soil samples taken from grazed sites, and more than 20 seedlings emerged from soil samples from ungrazed sites [111].

For information about sweetclover and fire-disturbed sites, see the discussion on Long-term fire effects and postfire succession.

FIRE EFFECTS AND MANAGEMENT

SPECIES: Melilotus alba, M. officinalis

- FIRE EFFECTS
- FUELS AND FIRE REGIMES
- FIRE MANAGEMENT CONSIDERATIONS

FIRE EFFECTS:

- **Immediate fire effect on plant**
- **Postfire regeneration strategy**
- **Fire adaptations**
- **Plant response to fire**

Immediate fire effect on plant: Sweetclover is killed or top-killed by fire. Often 2nd-year plants survive fire better than 1st-year plants, and survival is generally reduced if fires burn when plants are actively growing [38,96,128].

Postfire regeneration strategy [232]:
Caudex or an herbaceous root crown, growing points in soil
Ground residual colonizer (on site, initial community)
Secondary colonizer (on- or off-site seed sources)

Fire adaptations: Sweetclover is well adapted to survive fire. Established 2nd-year plants often survive dormant-season fires [96,128], and seed survival and subsequent establishment are likely even if growing-season fires kill all plants. Seeds are heat tolerant [29,200], and germination can be stimulated by fire [129,197,218].

Sprouting after fire: The potential for sweetclover to sprout after fire may depend on plant phenology and fire timing. Sprouting after aboveground damage may be limited to 1st-year plants with large crown buds [289] or 2nd-year plants that have not yet produced flower buds (review by [45]). By late summer or early fall, 1st-year sweetclover plants have considerable carbohydrate stores and regrowth potential [118,157,216,289]. Additional protection from fire may be provided by sweetclover’s contractile roots, which pull the root crown underground in the fall and protect its buds from extreme temperatures (review by [251]). In oak savannas on the Sherburne National Wildlife Refuge, "vigorous" yellow sweetclover sprouts were observed the growing season following a spring prescribed fire [182].

Heat tolerance of seeds: Sweetclover seeds can survive high temperatures, and heating may increase germination.

Substantial increases in germination of hard sweetclover seed required high temperatures and/or long-duration heating. After 5 days at 150 °F (66 °C), germination of hard seeds was up to 10% greater than germination of unheated seeds. When seeds were heated at 220 °F (100 °C) for 1 minute, hard seed germination increased only 2.5%. When heated at the same temperature for 4 minutes, germination increased significantly (9.1%) (P<0.05) [200]. Yellow sweetclover emerged from many soil samples collected from several habitat types in or near Yellowstone National Park; the samples were heated for an hour at temperatures of 120 to 300 °F (50-150 °C) [29]. However, the results suggested that emergence of yellow sweetclover was affected more by soil sampling location than high temperature exposure. White sweetclover seedlings began emerging from steer and horse manure that reached 158 °F (66 °C) within 2 weeks of composting. Up to 22% percent of white sweetclover seed was viable after 1 month in composting manure, and 4% of seed was viable after 2 months [92].

Plant response to fire: Survival and increased abundance of sweetclover are likely following dormant-season fires [96,129]. Survival of established plants is less likely and abundance may be reduced by growing season fires [129,295]; however, emergence from the seed bank will likely allow sweetclover to persist even after growing-season fires. Sweetclover persists on annually burned sites and has been reported on sites burned annually for up to 10 years [105].

Postfire seedling emergence: In several studies, fire stimulated germination of soil-stored sweetclover seed. Dormant-season (early spring or late fall) fires encouraged white sweetclover seed germination in tallgrass prairie at the University of Wisconsin Arboretum [129]. White sweetclover germination was stimulated by an early spring prescribed fire in a tallgrass prairie in Minnesota [96]. After a mid-March fire, abundant white sweetclover seedlings occurred in a sub-climax prairie near Seymour, Illinois [197]. In the laboratory, researchers found that 60% of yellow sweetclover seeds germinated on intact burned sod collected from a recently burned tallgrass prairie in eastern Kansas [218].

Establishment on burned sites: Sweetclover may establish in early succession on burned sites from off-site seed sources. Although yellow sweetclover did not occur in prefire vegetation and was rare in soil samples collected from a dense ponderosa pine forest in Lawrence County, South Dakota, yellow sweetclover was present in the 2nd postfire year. In 1,080 soil samples collected prior to the early May prescribed fire, just 1 yellow sweetclover seedling emerged. The prescribed fire produced flame lengths of up to 4.3 feet (1.3 m) and burned when winds were light, relative humidity ranged from 30% to 60%, and temperatures were 54 to 70 °F (12-21 °C) [287]. Yellow sweetclover was "widespread" in 2-year-old burned pinyon-juniper vegetation in Mesa Verde National Park, Colorado, but absent in the 1st postfire year. The fire burned in August. The study did not provide comparisons to prefire or unburned conditions [62]. When burned and adjacent unburned sites within the blackbrush (*Coleogyne ramosissima*) vegetation zone in southwestern Utah were compared, yellow sweetclover was restricted to a site burned 2 years earlier and did not occur on any unburned sites. Perennial grasses had been seeded on the burned site [23], suggesting that yellow sweetclover may have been a seed contaminant. While early colonization of burned sites by sweetclover is common, in Alaska sweetclover had not colonized newly exposed mineral soils on 1- to 2-year-old burned sites. Yellow sweetclover occurred on adjacent unburned sites, but researchers suggested that the low pH of the upland soils prevented establishment even after fire [37].

In many areas sweetclover was intentionally seeded on burned sites, although it did not always establish where seeded. Explanations for failed and successful seedling establishment were not often apparent. Yellow sweetclover established on only 4 of 10 burned sites seeded the day after a mid-May prescribed fire in grand fir/Oregon boxwood (*Abies grandis*/*Paxistima myrsinites*) habitats in north-central Idaho. Yellow sweetclover on these sites did not persist to the 4th postfire year [140]. In northern Idaho, seeded sweetclover established on most but not all burned ponderosa pine and mixed-conifer sites. Establishment failures were not consistently associated with fire season, seeding season, or habitat type [214]. In the Black Hills of South Dakota, establishment and growth of sweetclover were greater on a burned site with fine soils than on a burned site with coarse soils. Yellow sweetclover was seeded about 8 months after the early September fire, which was severe enough to expose mineral soil and kill almost all trees. Although seedlings occurred on both soil types in the 1st postfire year, in the next year, seedlings were "spindly and weak" on the coarse soils and tall and vigorous on the fine soils. Conditions were "unusually dry" during these first 2 postfire years. In the 3rd and 4th postfire years, seedlings were more common in fine than coarse soils, but few seedlings survived to their

2nd year [179]. On the east slope of the Cascades in Washington, yellow sweetclover establishment from a seed mix was poor on severely burned ponderosa pine-Douglas-fir forests. Abundance of yellow sweetclover seedlings was even lower where seeded sites were fertilized [247]. Yellow sweetclover failed to establish when seeded after logging and fall burning in a lodgepole pine stand in northeastern Washington [59] and after a July fire in big sagebrush and pinyon-juniper habitats in central Utah [30].

Abundance changes associated with fire: Sweetclover commonly occurs on burned sites, and often abundance is greater on burned than unburned sites, especially in grasslands. The frequency of sweetclover was similar in burned and unburned upland bluegrass (*Poa* spp.)-sweetclover communities in North Dakota's Oakville tallgrass prairie. Frequency decreases were nearly equal on both burned and unburned plots between the 1st and 2nd postfire growing seasons. Neither fire season nor severity was reported [86]. In Wind Cave National Park, South Dakota, logistical regression analyses revealed that white sweetclover was most common on low-elevation, "recently" burned (=5 years prior) mixed-grass prairie and open ponderosa pine woodlands [177]. In denseflower cordgrass (*Spartina densiflora*) marsh in Venezuela, yellow sweetclover frequency was 12% on 1-year-old burned site and 2% on a similar unburned site [150].

Fire season: Although fire studies vary, sweetclover abundance seems to increase or remain the same following single, dormant-season (early spring or late fall) fires. Growing-season fires may reduce sweetclover abundance. In a tallgrass prairie in the University of Wisconsin Arboretum, May fires were more effective than dormant-season fires in killing white sweetclover. More 1st-year plants survived to maturity on sites burned in the dormant season than on unburned sites [129]. Information about fire season as it relates to sweetclover control is presented in the Use of prescribed fire as a control agent discussion below.

In the following fire studies, sweetclover abundance was often reduced by summer burning but usually increased after fall or winter fires. When plants were burned with a propane torch in late June or early July along the Nenana River in Alaska, 1st-year white sweetclover were killed, and density of 2nd-year burned plants was significantly lower (P=0.05) than density of 2nd-year unburned plants. At the time of burning, 1st-year white sweetclover were in the 6- to 12- leaf stage, and 2nd-year white sweetclover were 2 to 3 feet (0.5-1 m) tall and flowering. For 2nd-year plants, total viable seed production was 95 seeds/ft² for burned plants and 3,293 seeds/ft² for unburned plants [38]. For more on using fire to control sweetclover in Alaska, see Use of prescribed fire as a control agent. By early May, there were "carpets of white sweetclover seedlings" on fall-burned, little bluestem (*Schizachyrium scoparium*)-dominated prairie in Mason County Illinois. Frequency of white sweetclover was 4.4% before the fire and 22.2% following the fire. The "moderately hot" fire burned in mid-November after dew from a heavy frost had dried. Winds averaged 15 miles (24 km)/hour, and relative humidity averaged 70%. There were patches of unburned vegetation [210]. Conversely, in central North Dakota, land managers reported that yellow sweetclover was usually "reduced or completely eliminated" by fall fires, but details were lacking [51].

In tallgrass prairie in Minnesota, fire timing affected 1st- and 2nd-year white sweetclover plants differently. An early May fire stimulated seed germination and growth of 1st-year plants but killed 2nd-year plants. Second-year plants were 2 to 6 inches (5-15 cm) tall at the time of the May fire, and survivors were restricted to low, wet areas. July fires killed most 1st- and 2nd-year plants. Survival in one case was attributed to delayed development and low fire temperatures on wet sites, especially affecting 2nd-year plants; survival in another case was attributed to the presence of gopher mounds, which shielded the plants from flames [96].

Although sweetclover survival and changes in abundance are related to plant dormancy and fire timing, establishing the strength of these relationships can be difficult. In some fire studies it is difficult to determine whether fires occurred while sweetclover was dormant, because of year-to-year regional and seasonal variations. Assessing sweetclover's phenology at the time of a fire is even more difficult when studies fail to report an exact fire date. In northern Illinois, white sweetclover was abundant on burned and mowed restored prairies during the treatment year and the following year. Burning occurred in mid-March, and mowing occurred in late June [193]; the phenological stage of white sweetclover at the time of treatments was not reported. A year after a “spring” prairie fire in Dickinson County, Iowa, there were 6-foot (1.8 m) tall white sweetclover plants producing seed. Dense white sweetclover growth "smother(ed) everything else" on the burned area, whereas white sweetclover produced little to no cover in the unburned area. White sweetclover abundance and growth did not increase on all burned quadrats [2]. In montane grasslands in Rocky Mountain National Park, sweetclover cover was reduced from prefire levels by 82% ($P<0.01$) within 14 months of mid- to late-May burning with a propane torch. Soil temperatures reached 120 °F (48 °C) at 2 inches (5 cm) deep and 84 °F (29 °C) at 4 inches (10 cm). On unburned plots, sweetclover cover increased by 35%. Without information about sweetclover's phenological stage at the time of burning, it is difficult to say whether this study supports or refutes the trends regarding the negative effects of dormant-season fires and the positive or neutral effects of growing-season fires on sweetclover abundance [295]. Sweetclover cover was greater on the majority of Tewaukon National Wildlife Refuge old-field sites that burned in May or June, than on unburned sites the year after fire [178].

Fire severity: Sweetclover tolerates severe fire. When low-, moderate-, and high-severity burned areas are compared, sweetclover is often more abundant on the most severely burned sites, with the possible exception of burned slash pile microsites. After a May fire in a recently logged ponderosa pine forest in Arizona's Coconino National Forest, yellow sweetclover "seemed to benefit most" from severe burning. Logging occurred 2 years before the fire, and although yellow sweetclover was in the seed mix used to revegetate logging roads, the researcher indicated that this had "minimal" effect on herbage production estimates. Severely burned areas experienced crown fires and nearly 100% tree mortality [12]. After large wildfires burned between 20 June and 26 July in ponderosa pine forests in northern Arizona, yellow sweetclover occurred on severely burned sites (cover 1%) but not on moderately burned or unburned sites. Moderately burned sites had little to no tree mortality but some crown scorch. Severely burned sites had nearly complete tree mortality [40]. In east-central Arizona, yellow sweetclover occurred on low- and high-severity burned sites by the 2nd postfire year following the Rodeo-Chediski fire that burned from 18 June to 7 July [133]. Yellow sweetclover was restricted to the lightly burned interspaces 5 years after slash piles burned in Colorado pinyon-Utah juniper (*Pinus edulis*-*Juniperus osteosperma*) woodlands in the Coconino National Forest. Yellow sweetclover did not occur on unburned plots or beneath slash burns [94]. However, the transient nature of biennial sweetclover populations means that assessments of only the 5th postfire year may have missed early, short-lived populations.

Tolerance of high-severity fires was not restricted to Arizona forests and woodlands. One and two years after prescribed fires in ponderosa pine forests in Montana's Missouri River Breaks, the estimated biomass of yellow sweetclover was significantly ($P<0.10$) greater on severely burned than merely “scorched” sites. Yellow sweetclover did not occur on unburned sites. Prescribed fires occurred in late May or early June, and precipitation was below normal following the fires. Abundance of trees with 1- to 3-inch (3-8 cm) DBH was reduced by 93% in "scorched" areas. In severely burned areas, all trees of that size were killed [297]. Within the first 4 postfire years in boreal mixed-wood forests of southeastern Manitoba, white sweetclover occurred on severely burned sites but not scorched or lightly burned sites. The early May wildfire lightly burned the litter on scorched sites, burned the litter but consumed little duff on lightly burned sites. On severely burned sites, the fire consumed the litter and duff layers and partially consumed organic matter in the soil surface horizon. White sweetclover cover was low (<0.1%) on the severely burned site but did not occur at all in 10-year-old or undisturbed boreal stands. Researchers suggested that white sweetclover emerged from transported seed, so fire severity may not have affected emergence [271]; however, the long-lived white sweetclover seed bank and heat tolerance of seeds suggest that seed bank germination would be difficult to rule out with certainty.

Repeated fire: Sweetclover populations can survive repeated fire. On a 23-year-old field in the Forest Glen County Preserve of east-central Illinois, the prefire frequency of white sweetclover was 8%. After the 1st prescribed fire on 3 March, white sweetclover frequency was 4%, and after a 2nd prescribed fire on 30 March the next year, white sweetclover frequency was 8%. Frequencies were not significantly different between any years [104]. Cover of white sweetclover increased with fire in a *Spartina argentinensis* grassland in Argentina. Two years after the 1st July (winter) fire, white sweetclover cover on burned and unburned plots was 1.5% and 0.2%, respectively. Six months after a 2nd fire (August, also winter), cover was 1.6% on burned and 0.7% on unburned plots [60].

Sweetclover's persistence on repeatedly burned sites may be affected more by fire season than fire frequency [105], and a combination of growing- and dormant-season fires has been used to control sweetclover (see Use of prescribed fire as a control agent). On the Schaefer Prairie in Minnesota, an early spring fire in 1986 followed by a May fire in 1987 caused a significant reduction in sweetclover abundance (Johnson 1987 personal communication cited in [55]). In tallgrass prairie in Minnesota, a spring fire occurred in 1969 (no exact date provided). The site was mowed in 1971, and then portions of the prairie were burned a 2nd time within 5 years of the 1st spring fire. Following the 1st fire, white sweetclover growth was dense. Density of 1st-year plants was greatest on the site burned again on 1 May 1974, and density of 2nd-year plants was greatest on the site burned again on 21 April 1973 [96]. Additional details from this study are available in the previous Fire season section.

Density* of white sweetclover by age class on once- and twice-burned tallgrass prairie [96]			
Age class	Burned spring 1969 and 1 May 1974	Burned spring 1969	Burned spring 1969 and 21 April 1973
1st year white sweetclover/m²	1.4	0.3	0**
2nd year white sweetclover/m²	0.025	0.2	6.5
*Density of 1st-year plants was measured 5 September 1974 and density of 2nd-year plants was measured 8 July 1974. **Before measuring 1st-year plant density, this plot burned a 3rd time in mid- or late July (this fire killed all 1st-year plants).			

Repeated growing-season fires may reduce sweetclover abundance, but repeated, even annual dormant-season fires rarely reduce sweetclover abundance. In an old field planted with prairie species in the University of Wisconsin Arboretum, plots were burned annually or biennially (3 to 6 times burned) in March, May, or October. White sweetclover was restricted to a shallow drainage wash in the study area, but density of white sweetclover in this wash ranged from a low of 133 plants/100 ft² on unburned plots to a high of 1,165 plants/100 ft² on March-burned plots. Density values were intermediate on May-burned plots. White sweetclover abundance was not reported for October-burned plots and abundance differences between annual or biennial frequency were not reported [44]. Density was likely evaluated within 2 years of the last fire. On the Aurora prairie in South Dakota, sweetclover was abundant after late-April fires that occurred in 1981, 1982, 1983, and 1984; but after a mid-May fire in 1987, sweetclover abundance decreased dramatically, although there were some surviving plants (Wells 1987 personal communication cited in [55]). On the tallgrass Konza Prairie in Kansas, yellow sweetclover was "essentially absent" from areas burned annually in April, but was "becoming common" in an area burned annually in November [105].

Fire effects on reproduction: Dormant-season fires may increase the reproductive potential of sweetclover, while growing-season fires may decrease it. White sweetclover flower production increased or did not change, while yellow sweetclover flower production was reduced after a prescribed fire in a tallgrass prairie in northwestern Minnesota on 2 May [184]. Differences between white and yellow sweetclover flowering on burned mesic prairie may relate to phenology. Because yellow sweetclover was likely more mature than white sweetclover at the time of the fire [229,267], yellow sweetclover may have suffered more damage than white sweetclover. Along the Nenana River in Alaska, white sweetclover seed production was much lower for plants burned in late June or early July than for unburned plants. Total viable seed production for burned plants was 95 seeds/ft² and for unburned plants was 3,293 seeds/ft² [38]. At the Retzer Nature Center prairie in Wisconsin, 2nd-year sweetclover seed production was less than 5% of "normal" after a single mid-May fire [209].

Long term fire effects (postfire succession): Generally, sweetclover abundance decreases as time since last fire increases, especially in woody vegetation types. However, in northern Arizona ponderosa pine/bunchgrass communities that burned severely within the last 40 years, yellow sweetclover still occurs and sometimes dominates [135]. In burned Douglas-fir-Rocky Mountain juniper vegetation in the Missouri River Breaks region of central Montana, yellow sweetclover cover ranged from less than 1% to 12% on sites burned 1 to 19 years earlier. Yellow sweetclover did not occur on sites unburned for 100 years or more [56]. In big sagebrush vegetation on southern Idaho's Snake River Plain, yellow sweetclover cover was low on sites burned and seeded 7 years earlier and was absent from sites burned and seeded 14 to 17 years earlier [46]. Yellow sweetclover persistence was even more brief after being seeded in burned pinyon-juniper stands in Jarvies Canyon in northeastern Utah. Yellow sweetclover produced tall plants and high cover on sites burned 1 to 3 years earlier, but plants were absent from sites burned 4 to 11 years earlier. In the study area, yellow sweetclover is not considered invasive and is restricted to roads and other frequently disturbed sites [77].

FUELS AND FIRE REGIMES:

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

Fuels: As of 2010, there was little information about sweetclover fuel characteristics. During an early May prescribed fire in the Curtis Prairie in Madison, Wisconsin, fire did not carry well through yellow sweetclover patches occupying a natural drainage [74]. Whether poor fire spread was a result of drainage, plant characteristics, or other factors affecting fire behavior is unknown.

Fire regimes: Information on the typical fire regimes in native sweetclover habitats was lacking. In North America, sweetclover occurs in communities with wide ranging fire regime characteristics. As of 2010, effects of large, invasive sweetclover populations on fire frequency or fire severity were not described. The complete FEIS Fire Regime Table provides fire regime information for many vegetation types and plant communities in which sweetclover may occur.

FIRE MANAGEMENT CONSIDERATIONS:

Preventing postfire establishment and spread: The potential for sweetclover establishment on burned sites is high. A long lived seed bank, potential for long-distance seed dispersal, heat-induced germination of hard seeds, and tolerance of early-seral conditions, make sweetclover establishment, persistence, and spread likely on burned sites.

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

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

For more detailed information on these topics see the following publications: [3,18,78,255].

Use of prescribed fire as a control agent: Under some circumstances, fire can be used to control sweetclover. Often dormant-season fires are used to stimulate germination of the soil-stored seed, then growing-season fires are used to kill 2nd-year plants and prevent subsequent seed production [129]. Multiple fires in different seasons are typically necessary to produce large decreases in sweetclover abundance ([96], review by [55]). Fires will not likely eradicate sweetclover, so follow-up treatments and long-term management plans are typically necessary. Burned areas should be monitored carefully, because patchy or low-severity fires may leave surviving plants (review by [55]). The effects of prescribed fire on associated native species and the feasibility of burning also need to be considered when developing a fire management plan for sweetclover control (see Other considerations).

Sweetclover abundance can be reduced by a single growing-season (May, June, or July) fire. Along the Nenana River in Alaska, 1st-year white sweetclover plants were killed and the density and seed production of 2nd-year plants was reduced by burning with a propane torch in late June or early July [38]. In the montane grasslands of Rocky Mountain National Park, sweetclover cover was reduced by 82% within 14 months of mid- or late-May burning in plots heavily invaded by sweetclover. Native vegetation, grass, and perennial vegetation cover increased on burned plots. The researcher suggested sweetclover could be controlled by burning in the spring, when plants were growing but before they had bolted [295]. At the Retzer Nature Center prairie in Wisconsin, 2nd-year sweetclover cover in dense patches was reduced by up to 85% after a single mid-May fire. Seed production in burned areas was less than 5% of "normal". Fires that occurred when sweetclover basal stems were completely shaded by the current year's growth were most effective in reducing abundance [209].

Repeated growing-season or a mixture of growing- and dormant-season fires are recommended for sweetclover control in northern Great Plains and Great Lakes prairies, where sweetclover is often invasive. A review suggests that 3 to 5 years of successive May or June fires can control sweetclover seed production (review by [55]). On the Aurora prairie in South Dakota, sweetclover was abundant following 4 years of annual late-April fires but decreased dramatically following a single mid-May fire (Wells 1987 personal communication cited in [55]). On the Schaefer Prairie in Minnesota, an early spring fire followed by a May fire the next year caused a significant reduction in sweetclover abundance (Johnson 1987 personal communication cited in [55]). After evaluating the effects of various prescribed fires in tallgrass prairie in Minnesota, Heitlinger [96] concluded that white sweetclover could be suppressed by annual fires in early May when 2nd-year shoots were visible or by biennial fires in early July before 2nd-year plants produced seed. Heitlinger also found that germination of white sweetclover was stimulated by an early spring fire. An early spring fire followed by fires in May or early July would likely deplete the seed bank and minimize seed production [96]. Heitlinger's prescribed fire studies and recommendations are also discussed in the Repeated fire and Other considerations sections.

Probably the most thorough and descriptive study on the use of fire to control white sweetclover was conducted by Kline [128,129] in the tallgrass Curtis Prairie in the University of Wisconsin-Madison Arboretum. The prescribed fire program most successful in controlling white sweetclover was as follows: an early-spring (dormant-season) fire in year 1, a May (growing-season) fire in year 2, no fire in years 3 and 4. This prescribed fire program was repeated several times with: another early-spring fire in year 5, another May fire in year 6, and 2 more years without fire. Mortality of 2nd-year plants was high on plots burned between 1 and 15 May. After the 1st May fire, the frequency of white sweetclover was 5% to 10%, and after a 2nd May fire, white sweetclover frequency was 0% to 5%. On unburned plots, the frequency of white sweetclover was 93% to 100%. Dormant-season prescribed fires in early spring or fall stimulated white sweetclover germination and increased plant survival through the 1st year. Two consecutive dormant-season fires failed to control white sweetclover and produced a high frequency of both 1st- and 2nd-year plants. Control of white sweetclover with fire was more difficult on recently disturbed sites, steep and dry sites, and sites with both 1st and 2nd year plants [128,129]. Kline's prescribed fire studies and descriptions of fire effects are also discussed in the Fire season and Other considerations sections.

Other considerations: Although sweetclover may be controlled and managed through a combination of repeated dormant- and growing-season fires, the frequency and/or timing of these fires may negatively impact native vegetation and wildlife. Dormant- and growing-season fires that largely decreased white sweetclover frequency in tallgrass prairie in Wisconsin also reduced the frequency of native forbs [129]. A land manager for the small Tomlinson Pioneer Cemetery Prairie indicates that a spring fire every 4 years promotes a diversity of grasses and forbs but also promotes germination and survival of sweetclover. Although more frequent fires provide better sweetclover control, frequent fires typically increase native grass abundance while reducing native forb abundance (Hanson 1987 personal communication cited in [55]). In Minnesota, fires in May can negatively affect nesting birds. Because of this, there is a negative public opinion of May fires, and prescribed burning is restricted to April. However, fires in April do not control sweetclover (Johnson 1987 personal communication cited in [55]). After studying a variety of prescribed fires that varied by season and frequency in tallgrass prairie in Minnesota, Heitlinger [96] suggests dividing a management area into small sections and staggering the timing and frequency of fires among these sections so that none receives the same treatment regimen. This small-scale management would ensure that the detrimental effects of fire would be short-lived and shared throughout the management area; unfortunately, the beneficial effects might also be short-lived.

Along the Nenana River floodplain in Alaska, white sweetclover density and seed production were reduced by burning with a propane torch, but fire spread is unlikely in these early-seral habitats. In Alaska, white sweetclover is generally restricted to roadsides and riparian areas where fuel loads are low and many native species are not well adapted to fire. Control of sweetclover with fire in Alaska would likely require small-scale flaming or burning operations that would be costly and time and labor intensive [38].

Altered fuel characteristics: Although one study found poor fire spread through dense sweetclover patches (see Fuels) [74], more information regarding fire behavior in areas heavily invaded by sweetclover is necessary before altered fuel characteristics and changes in fire regimes can potentially be attributed to sweetclover.

MANAGEMENT CONSIDERATIONS

SPECIES: Melilotus alba, M. officinalis

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

FEDERAL LEGAL STATUS:
None

OTHER STATUS:
Information on state-level noxious weed status of plants in the United States is available at Plants Database.

IMPORTANCE TO WILDLIFE AND LIVESTOCK:
Sweetclover is consumed by a variety of large and small, native and domestic herbivores. Sweetclover seeds and insect visitors can be important to birds (reviews by [84,240,241]).

Large mammals: Deer, antelope, elk, and livestock feed on sweetclover. When diets of co-occurring elk, deer, and livestock were compared, sweetclover was often a larger component of native ungulate diets than cattle diets.

Studies in the Great Lakes and western regions of the United States indicate that deer use of sweetclover can be heavy but may vary seasonally. In a prairie restoration area in Bloomington, Minnesota, white-tailed deer fed heavily on yellow sweetclover [58]. On the Mud Lake National Wildlife Refuge in Holt, Minnesota, the average use of sweetclover by white-tailed deer was 18.5% [109]. In a review of mule deer feeding habitats in the western United States, heavy use of yellow sweetclover in the summer was reported several times and heavy fall use was reported once. Several studies also reported moderate use throughout the year [134]. Within the Beaver Creek Watershed south of Flagstaff, Arizona, yellow sweetclover made up 0.6% of tame mule deer diets in June and 41.3% in July. Yellow sweetclover was not eaten in August or September [259]. On the Kaibab Plateau in northern Arizona, 7.7% of mule deer feeding observations were on white sweetclover in the first half of June. Observed feeding on white sweetclover was much lower from 16 June to 30 August [108]. In south-central New Mexico, fecal analyses indicated that yellow sweetclover averaged 2.7% of mule deer diets in September and 2.1% in March [152].

Utilization of sweetclover by pronghorn has been reported in Wyoming [97] and Montana [283]. In central Montana, yellow sweetclover was a greater proportion of summer pronghorn diets than white sweetclover. White sweetclover averaged 1% to 2% and yellow sweetclover averaged 12% to 29% of pronghorn summer diets. Yellow sweetclover was much more frequent than white sweetclover in the study area [283], which likely affected pronghorn diets more than preference.

In the majority of studies comparing the diets of native ungulates and livestock, sweetclover was more common in native ungulate than livestock diets. In grasslands and big sagebrush habitat types in north-central Montana, yellow sweetclover made up 27% of summer and a trace of winter mule deer diets based on rumen analyses. Yellow sweetclover made up 8% of summer cattle diets based on feeding site observations [53]. Based on 4 years of feeding habit observations in Montana's Missouri River Breaks, yellow sweetclover was 53% of elk, 44.5% of mule deer, and 26% of cattle total summer feeding use. Use of yellow sweetclover was much lower (12-14%) in winter and spring [149]. In north-central New Mexico, yellow sweetclover was 12% of pronghorn and cattle winter diets in a drought year but was not utilized in a year with above-normal precipitation. Yellow sweetclover was not a part of either species' spring diets in any year [226].

Livestock feed on sweetclover, but bloating is possible from consuming only sweetclover, and poisoning can occur if sweetclover hay is not properly cured. On the Blodgett Forest Research Station in central California, white sweetclover was most important in summer cattle diets. Based on fecal analyses, white sweetclover was 1.9% to 4.3% of July diets [121]. Although livestock bloating can occur with a diet primarily of sweetclover, this risk is reduced when dry roughage is available [117,220]. Sweetclover contains coumarin, which can break down into compounds that prevent blood clotting. These chemical changes occur when hay molds or is improperly cured. Internal hemorrhaging or excessive bleeding from small wounds can lead to death [10,48,188]. Death from internal hemorrhaging is more common in cattle than in sheep or horses [10].

Small mammals: Sweetclover has been reported in black-tailed jackrabbit, eastern cottontail, and prairie dog diets. In grasslands in Washington County, Colorado, sweetclover was important to jackrabbits in November and February [224]. In the winter, eastern cottontails fed extensively on small white sweetclover branches and shoots around the Green Pond near Syracuse, New York [249]. In the Conata Basin in western South Dakota, cover of yellow sweetclover was low and made up a small proportion of prairie dog diets. Cover of yellow sweetclover in the study area was 0.1% or less. Based on fecal analyses, yellow sweetclover was 0.3% of March prairie dog diet composition [258].

Birds: Sweetclover seeds and/or insect visitors are important forage for waterfowl, game birds, and song birds (reviews by [156,230,240]). As with mammals, bird use of sweetclover may vary by season. Sweetclover seeds were recovered from the crops of winter-killed gray partridge, ring-necked pheasants, and California quail. The largest volume (19.5%) of sweetclover was recovered from California quail crops. Much less sweetclover was recovered from summer- or fall-collected crops of any bird species [130]. In Idaho, sweetclover is important forage for sage grouse broods [4]. In Nevada, white-crowned sparrows, house finches, and mourning doves are commonly flushed from sweetclover vegetation when seeds are ripening. Sweetclover seeds are also utilized by Gambel's quail, California quail, and ring-necked pheasants in the Intermountain West (review by [84]). Up to 10% of Gambel's quail diets in Nevada were sweetclover (review by [156]). In the Nebraska Sandhills, yellow sweetclover was recovered from crops or gizzards of adult sharp-tailed grouse collected in the summer. Yellow sweetclover occurred in 18% of samples. Yellow sweetclover was not recovered from crops or gizzards of young sharp-tailed grouse [132]. In the Great Plains, yellow sweetclover attracts insects that are consumed by songbirds and upland game birds (review by [240]). In Minnesota, sweetclover occurred in gray partridge diets (review by [156]).

While sweetclover seed is eaten by many bird species, it may not be preferred. When dark-eyed juncos and Harris's sparrows were offered yellow foxtail (*Setaria pumila* ssp. *pumila*) and yellow sweetclover seed in captivity, daily consumption of yellow foxtail was 5 to 6 g/day and yellow sweetclover was less than 1 g/day. Hatchery-raised northern bobwhites consumed more than 12 g of yellow foxtail/day and less than 3 g of yellow sweetclover/day [175].

Insects: Sweetclover attracts a variety of insects. In a review, Turkington and others [251] suggest that white sweetclover attracts a wider variety of insects than yellow sweetclover. Bees commonly visit sweetclover plants [188,251] and are important to sweetclover pollination [55,144,285]. Early beekeepers were responsible for some of the early spread of sweetclover in North America [96]. In the Denver-Boulder metropolitan area of Colorado, researchers commonly found sweetclover pollen on native bees collected from native grasslands. Most collected bees were generalists from the Halictidae family. It is possible that native plants were experiencing decreased pollination because of high nonnative plant visitation rates, but this was not studied [100].

Insect diversity on sweetclover can be high. On eastern Minnesota prairies, 15 insect species were collected from yellow sweetclover and 19 from white sweetclover plants. Two insect species were unique to yellow sweetclover [195]. Along riparian areas of the Colorado River in the Grand Canyon, invertebrate densities were greatest from sweeps of white sweetclover and saltcedar. Researchers did 50 insect sweeps on 10 common native and 3 nonnative species (Stevens 1976 cited in [227]).

In Indiana and Wisconsin, sweetclover is a nectar source for 1st- and 2nd-generation adult Karner blue butterflies, which are endangered (review by [85]). White sweetclover was one of the most frequently selected nectar sources in the Indiana Dunes area. When another plant was within 7 feet (2 m) of white sweetclover, Karner blue butterflies selected white sweetclover over the other plant a significant number of times (P<0.01) [83].

Palatability and/or nutritional value: Sweetclover is considered high-quality, palatable wildlife and livestock forage [168,230], but if sweetclover is the only diet component or is improperly cured as hay, it can cause problems for livestock. Some indicate that sweetclover is higher quality forage than alfalfa [230], but forage quality declines as plants mature and become woody [220].

The nutrient content of sweetclover has been reported in the summer in Arizona [259] and throughout the growing season in Ohio [289]. White sweetclover seeds collected near Champaign, Illinois, averaged 4,687 cal/g [120].

Cover value: In the Great Plains, yellow sweetclover is used by game birds for nesting, brood rearing, and winter cover [240]). In parts of Canada, ring-necked pheasants nest in sweetclover stands [251].

OTHER USES:
Sweetclover has several medicinal and household uses. Sweetclover produces a coumarin compound that can be converted to dicoumarin, which is used medicinally as an anticoagulant [48]. Yellow sweetclover has also been used medicinally to treat external and internal inflammation and stomach and intestinal ulcers [10]. Sweetclover inflorescences have been used in eye lotions [151].

As its common name suggests, sweetclover has a pleasant smell. Northeastern "woodland" natives used dried white sweetclover leaves and flowers in teas [207]. Sweetclover leaves were also used to scent linens and sleeping quarters by early settlers [10] and members of Omaha and Dakota tribes [72].

Nurse crop: Several sweetclover growth characteristics make it attractive as a nurse crop in revegetation. Sweetclover produces strong and deep penetrating taproots that can loosen and aerate compacted soils. Roots are also the site for nitrogen fixation, and as roots decay, nitrogen availability is increased. These processes result in improved soil conditions for succeeding plants (review by [220]). Yellow sweetclover has been used successfully as a nurse crop revegetation of sagebrush ecosystems. Yellow sweetclover establishes and develops faster than seeded grasses and minimizes invasion by other, less desirable invasive species. In sagebrush habitats, yellow sweetclover generally decreases in importance as grasses increase in size and abundance [159].

Use of sweetclover as a nurse crop has been important to its spread throughout North America (see Introduction and spread in North America), and in many habitats, sweetclover can persist and delay development and success of native species (see Impacts on vegetation).

IMPACTS AND CONTROL:
Generally sweetclover is most invasive in grasslands and riparian areas. Sweetclover is commonly invasive in the upper Midwest and Great Plains regions [45,115]. In many prairies, sweetclover is associated with displacement of native species by limiting sunlight and moisture and changing nutrient availability (reviews by [45,222]). Some have referred to white sweetclover as the prairie "restorationists nightmare" [203]. When Wisconsin's plant and natural area experts were surveyed, white sweetclover ranked 20th and yellow sweetclover ranked 24th out of 66 invasive plants having negative ecological impacts in native communities [196].

Although invasive sweetclover populations are common in the Midwest and Great Plains, they are not restricted to these areas. In montane grasslands in Rocky Mountain National Park, Colorado, sweetclover has spread rapidly.

Between May and the end of the growing season in 1998, sweetclover populations expanded 3 feet (0.8 m). In 1999, population boundaries extended 6 feet (1.8 m) beyond those mapped in May 1998 [296]. In a New Jersey state-agency publication, sweetclover is reported in globally rare plant communities along the Delaware River. Agency officials cautioned that sweetclover has the potential to form dense stands, prevent native plant establishment, alter community structure, and disrupt succession [221]. As of 2005 in Alaska, white sweetclover was ranked among the states top 10 invasive plants based on potential distribution, ecological impacts, dispersal ability, and feasibility of control (review by [225]). Dense patches of white sweetclover also occur where narrow endemics, Williams' milkvetch (*Astragalus williamsii*) and Setchell's willow (*Salix setchelliana*), grow in Alaska [37].

While sweetclover can be invasive, in many areas it is not a priority for management and is restricted to disturbed sites. The eastern region of the Forest Service considers sweetclover "moderately invasive" and indicates that native species displacement is only occurring on a local scale [253]. Sweetclover is only "occasionally invasive" according to the Virginia Department of Conservation and Recreation [266]. In Canada, white sweetclover was number 55 in a prioritized list of 81 species thought to seriously reduce biodiversity in natural areas [27]. Based on a review of available literature and solicited opinions of Canadian botanists, yellow and white sweetclover were described as "primarily species of disturbed sites" with "limited" impacts but abilities to "compete well" in natural areas [286]. A model that incorportated climatic ranges, biological traits, and habitat preferences predicted that sweetclover posed a moderate risk for establishment and proliferation in Riding Mountain National Park, Manitoba, but in their review, researchers noted that sweetclover is already invasive in some Canadian natural areas and is an "ephemeral" threat in prairies, open woodlands, and along stream banks [180].

Site conditions including potential natural vegetation type, elevation, soils, and climate are most likely to affect invasibility by sweetclover. Sweetclover is generally more restricted to disturbed sites in forested and alpine ecosystems than in grassland habitats. In mixed-grass prairies of North Dakota's Theodore Roosevelt National Park, yellow sweetclover was related more to native vegetation type than disturbance [139]. In mixed woods in northern Saskatchewan's southern boreal forest region, sweetclover occurred only along roads and not on sites logged or burned in the last 15 years. Sweetclover was classified as a "lesser threat" and a low priority for management or control [242]. Yellow sweetclover occurred only in disturbed areas above and below timberline in subalpine fir/grouse whortleberry and/or Idaho fescue-slender wheatgrass (*Festuca idahoensis*-*Elymus trachycaulus*) habitats in the Northern Rocky Mountains [276]. In mature pinyon-juniper stands in Jarvies Canyon in Daggett County, Utah, yellow sweetclover is not considered invasive and is restricted to roads and other frequently disturbed sites [77].

Impacts on vegetation:

Native grasses and forbs: The majority, but not all, greenhouse and field studies show that sweetclover negatively impacts native grass and forb recruitment and growth. In greenhouse experiments, C3 and C4 prairie grasses were seeded with and without yellow sweetclover in soil collected from the field in Fort Riley, Kansas. Grass abundance was lower with than without yellow sweetclover. Species richness and diversity increased over time without yellow sweetclover but decreased with it. Although most grasses germinated in the presence of yellow sweetclover, grass seedling survival was low. When seeded into established cover of western wheatgrass (*Pascopyrum smithii*) or smooth brome (*Bromus inermis*), yellow sweetclover germinated and grew well. In the greenhouse, yellow sweetclover grew rapidly, quickly shading grass seedlings. Several months into the experiments, soil moisture was lower in containers with than without yellow sweetclover, and in the early developmental stages, yellow sweetclover took up large amounts of nitrogen [47].

In montane grasslands in Rocky Mountain National Park, Colorado, abundance and cover of nonnative species were significantly greater in sweetclover-invaded patches, and abundance and cover of native species were significantly greater in uninvaded patches ($P<0.001$). Amounts of bare ground were always greater in invaded than uninvaded sites, and sweetclover patches occurred in "seemingly undisturbed meadows well beyond disturbance edges". Invaded sites supported the most grasses and uninvaded sites supported the most forbs, suggesting that community structure was altered by the presence of sweetclover [296].

Several native prairie forbs (pride of Ohio (*Dodecatheon meadia*), Canadian lousewort (*Pedicularis canadensis*), tall cinquefoil (*Potentilla arguta*), and Virginia mountainmint (*Pycnanthemum virginianum*)) were negatively associated with white sweetclover ($P<0.01$) in southeastern Wisconsin's tallgrass Chiwaukee Prairie. There were 859 white sweetclover plants in 40 disturbed (old roadbed) quadrats and none in 60 undisturbed quadrats. White sweetclover was positively correlated with soil potassium, phosphorus, pH, and moisture (P<0.01). Researchers suggested that native species may be unsuccessful in competition for light with white sweetclover, which often reaches over 5 feet (1.5 m) tall in the study area. The shallow, gravelly, highly mineral soils on old roadbeds could also inhibit native species establishment and growth [183].

Along the Healy and Nenana Rivers in interior Alaska, native seedling recruitment was significantly reduced in the presence of white sweetclover (P<0.05). In plots with white sweetclover, recruitment of natives was about half that in plots without white sweetclover. Native seedling mortality was 50% more likely in plots with than plots without white sweetclover. Shading by white sweetclover was considered the likely reason for reduced native species recruitment, but in greenhouse experiments, shading did not increase growing-season mortality of the native species evaluated, although winter mortality was greater for some shade-grown than sun-grown seedlings. In another experiment conducted outdoors, 2 native legumes, field locoweed (*Oxytropis campestris*) and alpine sweetvetch (*Hedysarum alpinum*), grew and survived well in sparse or dense 1st-year white sweetclover. These experiments indicate that the mechanism(s) by which white sweetclover limits native species recruitment is not obvious [225].

In Badlands National Park in southwestern South Dakota, yellow sweetclover had a "consistent" and "strong" positive relationship with native and nonnative plant species cover in a sparse vegetation type. Vegetation and plant interactions were monitored in the sparse vegetation type and mixed-grass prairie type. There were no consistent relationships between native or nonnative vegetation and yellow sweetclover in the mixed-grass prairie. In the sparse vegetation type, where the number of hospitable establishment locations is limited, yellow sweetclover acted as a nurse plant. Invasions by sweetclover could result in the loss of the unique sparse vegetation type through conversion to prairie [262].

Woody vegetation: Sweetclover may restrict woody plant establishment and growth. In at least one location, this restriction may serve to control a more aggressive nonnative species. Along the Hassayampa River in central Arizona, sweetclover seedlings were abundant in the dry surface zone following winter flooding. High cover of sweetclover seedlings "preempted" establishment of saltcedar; thus native community dominance and structure were sustained [237]. On a burned site in northern Arizona, growth of ponderosa pine seedlings was lower on sites seeded with yellow sweetclover than on unseeded sites. Two-year-old ponderosa pine seedlings were planted in the burned area in April of the 1st postfire growing season. Yellow sweetclover was seeded on one of the plantation sites 3 months after ponderosa pine seedlings were planted. After 2 years, ponderosa pine seedlings on the unseeded site averaged 12 inches (31 cm) tall and 1.4 cm in diameter and on the seeded site averaged 9.5 inches (24.4 cm) tall and 1.2 cm in diameter. Ponderosa pine seedling survival was not different between seeded and unseeded sites [57].

Impacts on soil nutrients: Because sweetclover is a nitrogen fixer, soil nitrogen levels may be greater on sites invaded by sweetclover. Increased nitrogen levels on sites invaded by sweetclover could alter species compositions (review by [277]), especially in nitrogen-limited ecosystems. Within 4 years of seeding yellow sweetclover on a rangeland impacted by drought and heavy grazing in western South Dakota, total soil nitrogen was significantly (P<0.01) greater on plots with than without yellow sweetclover [172]. During field studies in northern Utah, researchers found that up to 29% of nitrogen fixed by white sweetclover was transferred to crested wheatgrass (*Agropyron cristatum*) and was transferred distances of at least 10 inches (25 cm) [68]. In a review, researchers estimated that sweetclover could release inorganic N to mineral soil at a rate of about 12 kg/ha/year, which is 2 to 3 times higher than nitrogen fixation in native rangelands without sweetclover. Researchers suspected that increased nitrogen from sweetclover would favor invasive species over stress-tolerant, long-lived perennials adapted to low nitrogen accumulation rates. The researchers concluded their review with a plea to discontinue use of sweetclover in roadside revegetation and rangeland improvement until more is known about sweetclover's effects on ecosystems and where these effects may be most or least detrimental [141].

In Badlands National park in western South Dakota, yellow sweetclover's effects on nitrogen mineralization and nitrification rates were different in sparse vegetation and mixed-grass prairie. In the prairie, nitrogen mineralization and nitrification rates were not different on sites with high and low yellow sweetclover cover. In sparse vegetation, however, nitrogen mineralization and nitrification rates were higher on sites with high versus low sweetclover cover. Sparsely vegetated sites occur on highly erodible Aridisols and Entisols, and total vegetation cover is 5% to 10%.

Prairie vegetation occurs on deep, well drained, calcareous Mollisols, and total vegetation cover is 45% to 100% [263].

In montane grasslands in Rocky Mountain National Park, Colorado, available ammonium and nitrate were significantly less ($P<0.002$ and $P<0.09$, respectively) on sites invaded by sweetclover than on uninvaded sites. Available ammonium and nitrate were measured for 2 growing seasons. Invaded and uninvaded sites were essentially equal in past disturbance patterns and in exposure, slope, and aspect [294]. On the Nenana River in Alaska, the soil in areas with white sweetclover did not differ in ammonium, nitrate, or total nitrogen content from that of soils taken from uninvaded areas [37].

Impacts on ecosystem processes: In restored tallgrass prairie at Fermilab's National Environmental Research Park in Batavia, Illinois, cumulative daily exchange of carbon was much lower when sweetclover dominated than when it did not dominate aboveground biomass. In 2005 when white sweetclover occurred as a rosette and did not dominate aboveground biomass, the net ecosystem exchange was 437.7 g carbon/m². In 2006 when white sweetclover bolted, flowered, and dominated the aboveground biomass, and net ecosystem exchange was 239.8 g carbon/m². Because white sweetclover senesced by late July or early August in 2006, the photosynthetically positive active days were reduced by 42%, which may partly explain the reduced carbon exchange. While a dramatic decrease in carbon exchange occurred when white sweetclover dominated, in both study years, net ecosystem exchange was high compared to other published values for North American grasslands [81].

Impacts on wildlife habitat: When native and nonnative grasslands in eastern South Dakota and western Minnesota were compared, grassland bird species richness was lower in nonnative than native grasslands. Nonnative grasslands were dominated by smooth brome (*Bromus inermis*), yellow sweetclover, and intermediate wheatgrass (*Thinopyrum intermedium*) and supported 40% to 60% fewer bird species than native prairie [9].

Impacts on insects: A diversity and abundance of insects utilize sweetclover (see Insects) ([195], Stevens 1976 cited in [227]). In Indiana and Wisconsin, sweetclover is an important nectar source for the federally endangered Karner blue butterfly ([83], review by [85]). In Capitol Reef National Park, Utah, researchers think that sweetclover may be increasing the bee carrying capacity in riparian areas. Bees were collected from 11 to 31 July from 10 blooming plant taxa. From white sweetclover, 126 bees representing 19 taxa were collected. From yellow sweetclover, 50 bees representing 14 taxa were collected. Pollinator competition among native and nonnative plants was likely low during this sampling period, when there were few blooming species and many bees. Because sweetclover provided nectar and pollen when floral diversity was low and flowers were few at Capitol Reef, bees may have been supported longer with sweetclover than without [244].

Impacts on agriculture: Sweetclover may negatively impact agriculture. White sweetclover is associated with 28 viral plant diseases including beet curly tip, cucumber mosaic, and tobacco streak (review by [204]). If sweetclover infects wheat crops and is still green at harvest, wheat can take on a sweetclover odor; this is referred to as "sweetclover taint" (review by [251]).

Control: Timing is important to successful control of sweetclover. Controlling sweetclover before plants flower is important for seed bank depletion, and damaging plants when carbohydrate stores are lowest reduces the chances of recovery. In fields in Columbus, Ohio, sweetclover was "nearly impossible" to kill after large sweetclover crown buds were produced between August and November [289]. At the Agronomy Research Center in West Lafayette, Indiana, yellow sweetclover total nonstructural root carbohydrates were highest from November to December and were lowest in May. Defoliation in June caused a rapid decline in root carbohydrates, which lasted about 2 weeks [142].

When sweetclover is targeted for control, no matter what method is employed, the potential for other invasive species to fill the void must be considered [19]. Similarly, sweetclover may invade after other weedy species have been removed. Near Little Manatee River State Park in Hillsborough County, Florida, white sweetclover dominates the weedy flora in areas around a riverfront development project that were chemically and mechanically treated to eradicate cogon grass (*Imperata cylindrica*) [170]. Control of biotic invasions is most effective when it employs a long-term, ecosystem-wide strategy rather than a tactical approach focused on battling individual invaders [148].

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

Prevention: It is commonly argued that the most cost-efficient and effective method of managing invasive species is to prevent their establishment and spread by maintaining "healthy" natural communities [148,213] (e.g., avoid road building in wildlands [252]) and by monitoring several times each year [114]. Maintaining the integrity of the native plant community and mitigating the factors that enhance ecosystem invasibility are likely to be more effective than managing solely to control the invader [102].

Weed prevention and control can be incorporated into many types of management plans, including those for logging and site preparation, grazing allotments, recreation management, research projects, road building and maintenance, and fire management [255]. See the Guide to noxious weed prevention practices [255] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions.

Cultural control: Sweetclover abundance is often reduced when perennial vegetation cover is high. A review suggests that white sweetclover can be eliminated within about 2 years of establishing perennial species cover [49]. In a smooth brome-dominated old field in Regina, Saskatchewan, field experiments suggested that yellow sweetclover growth may be limited more by belowground than aboveground competition. Yellow sweetclover seedlings were smallest when grown with neighboring smooth brome plants intact. Yellow sweetclover seedlings were slightly larger in plots where the aboveground biomass of smooth brome was removed. Yellow sweetclover seedlings were significantly larger ($P<0.05$) than those previously described in plots where only the belowground smooth brome biomass was removed and in plots where all biomass was removed [70].

Physical or mechanical control: Hand-pulling, cutting, and mowing can be useful for controlling sweetclover. Hand-pulling has been successful for controlling small sweetclover populations on Nature Conservancy preserves across the country [250]. Hand-pulling is most effective when the ground is moist (early spring or late fall) and complete root removal is most likely. At these times, stress on associated vegetation should be low (reviews by [35,277]). Another review recommends that 1st-year sweetclover be pulled after the root crown has developed [45]. However, failure to remove the entire root could mean plant survival, since sweetclover is "nearly impossible" to kill after large crown buds are produced from August to November [289].

Results from cutting and mowing treatments to control sweetclover are mixed. Cutting may be most effective if done before large amounts of carbohydrates are stored (usually late summer), and cutting may be more effective on 2nd-year than 1st-year sweetclover plants. In fields in Wisconsin, growth of 1st-year sweetclover was monitored with and without cutting. Cutting occurred on 16 August, 2 September, 18 September, and 18 October. The largest increases in root size and carbohydrate storage occurred between the 18 September and 18 October sampling dates. Cutting on 18 September produced the greatest reductions in root size, weight, and available carbohydrates and nitrogen [216]. Along the Nenana River in Alaska, cutting 1st-year white sweetclover plants to a height of 1 inch (2.5 cm) did not decrease plant density but did decrease seed production. Cutting 2nd-year plants reduced both plant density and seed production. Cut plants produced 25 seeds/ft^2, and uncut plants produced 3,293 seeds/ft^2. However, only selective cutting would be appropriate management in Alaska, where mowing would likely damage native vegetation [38]. On a loess prairie in northwestern Missouri, about 30% of 2nd-year sweetclover sprouted after being cut as close to the ground as possible (Ladd 1987 personal communication cited in [55]).

Although a review suggests that sweetclover rarely sprouts if cut close to the ground before seeds are formed [35], mowing along roads seems to favor sweetclover populations (review by [251]); and on annually summer mowed and hayed plots in the tallgrass Konza Prairie in Kansas, yellow sweetclover persisted and was dominant in some years [105]. Stems should be removed from the treatment area if cutting occurs during or after flowering, to minimize the chance of adding viable seed to the seed bank (review by [45]).

Frequent and/or summer mowing may be most effective for sweetclover control. In a hay meadow in Lake County, Illinois, frequent (7-8 times/year) mowing reduced the abundance of white sweetclover [203]. In a Wisconsin tallgrass prairie, mowing in July substantially reduced white sweetclover [129]. However, late-June mowing in a restored prairie in northern Illinois did not reduce white sweetclover. Productivity of white sweetclover increased on the mowed area [193]. White sweetclover root growth was rapid in September near Ames, Iowa. Mowing just before this time may reduce the volume of overwintering roots and increase overwintering mortality. The volume of white sweetclover roots for plants mowed in late August averaged 51% of that of unmowed plants. Overwinter mortality for plants mowed in late August averaged 57.5%, for plants mowed in early September averaged 40%, for plants mowed in early October averaged 4.5%, and for unmowed plants was 1.5%. During the study period in this area, the winter was severe with several hard freezes in the absence of snow cover [157].

Biological control: Although no biocontrols have been released to control nonnative sweetclover, native sweetclover weevils may provide some control where they occur in large numbers [286]. Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. Refer to these sources: [261,290] and the Weed control methods handbook [250] for background information and important considerations for developing and implementing biological control programs.

Chemical control: Herbicides provide control of sweetclover. Herbicides may be most effective on 1st-year sweetclover (review by [251]) and when used with other control methods. In early May following a fall fire in little bluestem prairie in Mason County, Illinois, the burned site was covered with a "carpet" of white sweetclover seedlings. Seedlings were successfully controlled with herbicide [210]. In Alaska, several herbicide treatments were tested on white sweetclover populations. Most herbicide types and rates decreased white sweetclover biomass and seed production. Only 1 herbicide treatment eliminated seed production [38].

Herbicides are effective in gaining initial control of a new invasion or a severe infestation, but they are rarely a complete or long-term solution to weed management [21]. See the Weed control methods handbook [250] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals.

Integrated management: Sweetclover abundance can be reduced through integrated management designed to encourage native vegetation and limit sweetclover growth and reproduction. In restored prairies in southern Manitoba's Beaudry Provincial Park, white sweetclover cover decreased over time as plots were seeded, burned, and selectively mowed. White sweetclover cover averaged 10.6% on sites seeded 4 to 8 years earlier, 3.4% on sites seeded 9 to 12 years earlier, and 0.4% on sites seeded 13 to 16 years earlier. In the restoration area, early spring prescribed fires occurred every 5 years, and white sweetclover patches were mowed repeatedly [160].

Melilotus alba, M. officinalis: REFERENCES

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