Fire Effects Information System (FEIS)

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SPECIES: Potentilla recta

INTRODUCTORY

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AUTHORSHIP AND CITATION:
Zouhar, Kris. 2003. Potentilla recta. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.fed.us/database/feis/plants/forb/potrec/all.html [2018, April 6].

FEIS ABBREVIATION:
POTREC

SYNONYMS:
None

NRCS PLANT CODE [86]:
PORE5

COMMON NAMES:
sulfur cinquefoil
sulphur cinquefoil

rough-fruited cinquefoil
upright cinquefoil

TAXONOMY:
The currently accepted scientific name for sulfur cinquefoil is *Potentilla recta* L. (Rosaceae) [25,28,35,38,40,41,47,57,62,72,88,90,94].

Sulfur cinquefoil is closely related to other members of the genus *Potentilla*. Hybrids of sulfur cinquefoil and *P. hirta* are reported to occur naturally and have been produced under controlled conditions [27].

LIFE FORM:
Forb

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
As of this writing (2003), sulfur cinquefoil is listed as a noxious weed in 5 U.S. states and 1 Canadian province [87] See the Plants or Invaders databases for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: Potentilla recta

- GENERAL DISTRIBUTION
- ECOSYSTEMS
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GENERAL DISTRIBUTION:
The following information on the origin, North American introduction, and spread of sulfur cinquefoil is based on reviews [60,70,91], unless otherwise cited.

Sulfur cinquefoil is native to the eastern Mediterranean region of Eurasia. It occurs sparsely in England, and occurs in central and southern Europe from central France and Germany to central Spain, Sicily and the Middle East. It is found in western and central Asia to approximately 100 E longitude, and south to Asia Minor and northern Iran. Sulfur cinquefoil also occurs in the mountains of North Africa [91]. More recent field surveys of western, central, and southeastern Europe did not locate sulfur cinquefoil in the upper Rhine valley, Alsace, the Swiss Jura; the alpine regions of Switzerland, Italy, and France; or in eastern Austria, southern Hungary, and northern Romania, although these areas have been listed as within its distribution. The surveys did locate sulfur cinquefoil in Macedonia, northern Greece, western Turkey and Bulgaria [39].

The exact time and place of the original introduction of sulfur cinquefoil to North America is not known. The 1st collection of sulfur cinquefoil in North America was made sometime before 1900 in Ontario. In 1950 its reported distribution was from Newfoundland and Nova Scotia to Ontario, with scattered populations in southern British Columbia, and rapidly spreading. By this time, sulfur cinquefoil was also established in the northeastern U.S. and the Great Lakes region [91]. The first known collection in western North America was on western Vancouver Island in 1914. The earliest record of sulfur cinquefoil in the Columbia River Basin was in Idaho in 1934 [70]. By 1940 sulfur cinquefoil had also been identified in Washington [22].

In North America, sulfur cinquefoil occurs from the eastern coast of Canada and the northeastern seaboard of the U.S. to the Pacific coast of British Columbia, Washington, and Oregon. It is not found north of 53 N latitude. Heavy infestations occur in southern Ontario, Quebec, southern interior British Columbia, the Great Lake states, Montana, Idaho, Oregon and Washington. Many federal wilderness areas surveyed in the Rocky Mountain region report the presence of sulfur cinquefoil [55]. Scattered populations of sulfur cinquefoil occur in Manitoba, along the Pacific coast from British Columbia south into California [34,60,91], and west into northwestern Nevada [41] and Colorado [90]. In the Great Plains, sulfur cinquefoil is infrequent to locally common in disturbed areas and less frequent in prairies [28]. It extends south into Florida [94] and Texas [18]. The Plants Database provides a distribution map for sulfur cinquefoil.

Powell [60] describes the need for an accurate, comprehensive inventory of sulfur cinquefoil in British Columbia. He suggests inventories at a scale relevant to ultimate management units, that include geographic location, plant community type, seral stage, site characteristics, and size, density, and canopy cover of sulfur cinquefoil infestations. Inventories of this nature would help to establish ecological limits and to define potential distributions of sulfur cinquefoil and other nonnative, invasive species in North America. This information could provide objective direction for the nature, degree, and location of management activities. Inventory information can also serve as a baseline for monitoring population dynamics, and the effectiveness of various management activities [60].

The ecological amplitude of sulfur cinquefoil must be determined to confirm which ecosystems and habitat types are suitable to its establishment and persistence, and to define its distribution and potential areas of impact [60].

The following lists are meant to provide some idea of where sulfur cinquefoil might occur or be invasive, but provide no certainty without the aforementioned inventory information.

ECOSYSTEMS [24]:
FRES10 White-red-jack pine
FRES11 Spruce-fir
FRES13 Loblolly-shortleaf pine
FRES14 Oak-pine
FRES15 Oak-hickory
FRES17 Elm-ash-cottonwood
FRES18 Maple-beech-birch
FRES19 Aspen-birch
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine
FRES23 Fir-spruce
FRES25 Larch
FRES28 Western hardwoods
FRES29 Sagebrush
FRES32 Texas savanna
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES37 Mountain meadows
FRES38 Plains grasslands
FRES39 Prairie
FRES41 Wet grasslands
FRES42 Annual grasslands

STATES/PROVINCES: (key to state/province abbreviations)

UNITED STATES

AL	AR	CA	CO	CT	DE	FL	GA	ID	IL
IN	IA	KS	KY	LA	ME	MD	MA	MI	MN
MS	MO	MT	NE	NV	NH	NJ	NY	NC	ND
OH	OK	OR	PA	RI	SC	SD	TN	TX	VT
VA	WA	WV	WI	WY	DC				

CANADA

AB	BC	MB	NB	NF	NS	ON	PE	PQ	SK

BLM PHYSIOGRAPHIC REGIONS [10]:
1 Northern Pacific Border
2 Cascade Mountains
3 Southern Pacific Border
4 Sierra Mountains
5 Columbia Plateau
8 Northern Rocky Mountains
9 Middle Rocky Mountains
10 Wyoming Basin
13 Rocky Mountain Piedmont
14 Great Plains
16 Upper Missouri Basin and Broken Lands

KUCHLER [44] PLANT ASSOCIATIONS:
K005 Mixed conifer forest
K010 Ponderosa shrub forest
K011 Western ponderosa forest
K012 Douglas-fir forest
K013 Cedar-hemlock-pine forest
K014 Grand fir-Douglas-fir forest
K015 Western spruce-fir forest
K016 Eastern ponderosa forest
K017 Black Hills pine forest
K024 Juniper steppe woodland
K048 California steppe
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe
K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass
K066 Wheatgrass-needlegrass
K067 Wheatgrass-bluestem-needlegrass
K068 Wheatgrass-grama-buffalo grass
K069 Bluestem-grama prairie
K070 Sandsage-bluestem prairie
K074 Bluestem prairie
K075 Nebraska Sandhills prairie
K081 Oak savanna
K082 Mosaic of K074 and K100
K083 Cedar glades

K093 Great Lakes spruce-fir forest
K095 Great Lakes pine forest
K096 Northeastern spruce-fir forest
K098 Northern floodplain forest
K100 Oak-hickory forest
K101 Elm-ash forest
K107 Northern hardwoods-fir forest
K111 Oak-hickory-pine

SAF COVER TYPES [21]:
1 Jack pine
14 Northern pin oak
15 Red pine
16 Aspen
20 White pine-northern red oak-red maple
21 Eastern white pine
39 Black ash-American elm-red maple
42 Bur oak
46 Eastern redcedar
50 Black locust
63 Cottonwood
78 Virginia pine-oak
79 Virginia pine
107 White spruce
201 White spruce
206 Engelmann spruce-subalpine fir
210 Interior Douglas-fir
212 Western larch
213 Grand fir
215 Western white pine
217 Aspen
220 Rocky Mountain juniper
224 Western hemlock
227 Western redcedar-western hemlock
228 Western redcedar
229 Pacific Douglas-fir
235 Cottonwood-willow
237 Interior ponderosa pine
238 Western juniper
244 Pacific ponderosa pine-Douglas-fir
245 Pacific ponderosa pine
251 White spruce-aspen

SRM (RANGELAND) COVER TYPES [77]:
101 Bluebunch wheatgrass
102 Idaho fescue
104 Antelope bitterbrush-bluebunch wheatgrass
105 Antelope bitterbrush-Idaho fescue
107 Western juniper/big sagebrush/bluebunch wheatgrass
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
214 Coastal prairie
215 Valley grassland
301 Bluebunch wheatgrass-blue grama

302 Bluebunch wheatgrass-Sandberg bluegrass
303 Bluebunch wheatgrass-western wheatgrass
304 Idaho fescue-bluebunch wheatgrass
305 Idaho fescue-Richardson needlegrass
306 Idaho fescue-slender wheatgrass
307 Idaho fescue-threadleaf sedge
309 Idaho fescue-western wheatgrass
310 Needle-and-thread-blue grama
311 Rough fescue-bluebunch wheatgrass
312 Rough fescue-Idaho fescue
314 Big sagebrush-bluebunch wheatgrass
315 Big sagebrush-Idaho fescue
316 Big sagebrush-rough fescue
317 Bitterbrush-bluebunch wheatgrass
318 Bitterbrush-Idaho fescue
319 Bitterbrush-rough fescue
320 Black sagebrush-bluebunch wheatgrass
321 Black sagebrush-Idaho fescue
323 Shrubby cinquefoil-rough fescue
324 Threetip sagebrush-Idaho fescue
409 Tall forb
411 Aspen woodland
412 Juniper-pinyon woodland
422 Riparian
601 Bluestem prairie
602 Bluestem-prairie sandreed
603 Prairie sandreed-needlegrass
604 Bluestem-grama prairie
605 Sandsage prairie
606 Wheatgrass-bluestem-needlegrass
607 Wheatgrass-needlegrass
608 Wheatgrass-grama-needlegrass
609 Wheatgrass-grama
610 Wheatgrass
611 Blue grama-buffalo grass
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass
615 Wheatgrass-saltgrass-grama
709 Bluestem-grama
722 Sand sagebrush-mixed prairie
723 Sea oats
805 Riparian

HABITAT TYPES AND PLANT COMMUNITIES:
Sulfur cinquefoil occupies a wide variety of habitats in its native range in southeastern Europe and southwestern Asia, from marine shorelines to pine-dominated forests, and is most common on hillsides in grass- or shrub-dominated communities (Schaffner and Tosevski 1994, as cited by Powell [60]). Surveys in parts of western, central and southeastern Europe located sulfur cinquefoil mainly in pine-forest clearings and forest borders. Sulfur cinquefoil occurred in open grassland vegetation only in Bulgaria [39].

Sulfur cinquefoil populations in North America are commonly associated with roadsides, vegetation disturbance, abandoned agricultural fields, and "waste areas" [60,70,91]. According to Rice [70], sulfur cinquefoil can also invade "native plant communities that are remote from any apparent human disturbance," and is now common in natural grasslands, "shrubby areas," and open-canopy forests in the northwestern U.S. [66,70].

Rice [69] conducted a summary analysis of ecological and management data for 85 sites infested with sulfur cinquefoil in Montana. Sulfur cinquefoil was identified in ponderosa pine (*Pinus ponderosa*), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), spruce (*Picea* spp.), grand fir (*Abies grandis*), subalpine fir (*A. lasiocarpa*), western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), antelope bitterbrush (*Purshia tridentata*), skunkbush sumac (*Rhus trilobata*), western wheatgrass (*Pascopyrum smithii*), bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), rough fescue (*F. altaica*), and Kentucky bluegrass (*Poa pratensis*) communities. The majority of these sites had other nonnative invasive plants present, as follows:

Associated nonnative species	Percentage of 85 sites
spotted knapweed (*Centaurea maculosa*)	60
Dalmatian toadflax (*Linaria dalmatica*)	5
common St. Johnswort (*Hypericum perforatum*)	13
leafy spurge (*Euphorbia esula*)	2
field bindweed (*Convolvulus arvensis*)	1
Canada thistle (*Cirsium arvense*)	11
diffuse knapweed (*Centaurea diffusa*)	5
whitetop (*Cardaria* spp.)	2

Of the 27 species of cinquefoil found in Montana, 6 native cinquefoils (shrubby cinquefoil (*Dasiphora floribunda*), tall cinquefoil (*P. arguta*), sticky cinquefoil (*P. glandulosa*), slender cinquefoil (*P. gracilis*), horse cinquefoil (*P. hippiana*), and Pennsylvania cinquefoil (*P. pennsylvanica*)) and 1 nonnative cinquefoil, (silver cinquefoil (*P. argentea*)) occurred with sulfur cinquefoil on 1 or more of the 85 sites studied [69].

In British Columbia, sulfur cinquefoil is most commonly found in bunchgrass, ponderosa pine, interior Douglas-fir, and coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) biogeoclimatic zones. Sulfur cinquefoil is a transient component of dry subzones of interior cedar-hemlock and coastal western hemlock biogeoclimatic zones. Sulfur cinquefoil is also commonly associated with diffuse knapweed populations in British Columbia [60].

In Michigan, Werner and Soule [91] found sulfur cinquefoil occasionally in wood margins, but not under forest canopies. It is sometimes found invading dry, open woods such as aspen (*Populus* spp.) [88]. Sulfur cinquefoil may be found in fallow fields with the following plants: aster (*Symphyotrichum* spp.), staghorn sumac (*R. typhina*), western yarrow (*Achillea millefolium*), Queen Anne's lace (*Daucus carota*), Canada bluegrass (*Poa compressa*), Norwegian cinquefoil (*Potentilla norvegica*), eastern daisy fleabane (*Erigeron annuus*), garden yellowrocket (*Barbarea vulgaris*), silvery cinquefoil, smooth brome (*Bromus inermis*), and annual ragweed (*Ambrosia artemisiifolia*) [91].

Sulfur cinquefoil is also found on eastern Minnesota prairie sites [64].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Potentilla recta

GENERAL BOTANICAL CHARACTERISTICS:
Correct identification of sulfur cinquefoil is important if control strategies are planned, because sulfur cinquefoil may be confused with native cinquefoils, particularly slender cinquefoil (*Potentilla gracilis*). Seven varieties of slender cinquefoil have been identified [35], further complicating identification. The following contrasting characteristics are suggested to help separate sulfur cinquefoil from slender cinquefoil [70]:

Slender cinquefoil	Sulfur cinquefoil
short, spreading hairs on leafstalk and stem	longer hairs perpendicular to leafstalk and stem
few stem leaves; mostly basal leaves	numerous stem leaves; fewer basal leaves
smooth seed coat	net-like pattern on seed coat
most have a dense, woolly underleaf	sparse, stiff hairs; both sides of leaf are similar
short rhizomes	woody taproot with short branch roots
flowers brighter yellow	flowers paler yellow
leaves are green to gray	leaves more yellowish
about 20 stamens	25 or more stamens
leaflet serrations sometimes deep	leaflet serrations halfway to mid-vein

The following description of sulfur cinquefoil presents characteristics that may be relevant to fire ecology, and is based on descriptions from several sources [6,20,28,47,91], unless otherwise cited. It is not meant for identification. Identification guidelines, line drawings, and color photos are available (e.g. [66]). Keys for identification are also available (e.g. [28,47]).

Sulfur cinquefoil is a perennial forb with a short caudex attached to a woody taproot. Sulfur cinquefoil roots are persistent and may have some lateral growth, but have no rhizomes [68]. Sulfur cinquefoil has 1 to several slender, erect, hairy stems that are 8 to 30 inches (20-80 cm) tall. The upper portion of the stem may be branched. Sulfur cinquefoil stems bear many palmately compound leaves with 5 to 9 leaflets that are 1 to 3 inches (3-8 cm) long and 0.2 to 1 inch (0.5-2.5 cm) wide, and covered on both sides with sparse, stiff hairs. Lower leaves have long petioles and upper leaves have shorter or no petioles and fewer leaflets. Sulfur cinquefoil flowers are many, and are borne in open, branched, flat-topped inflorescences above the principal foliage. Flowers are 0.6 to 1 inch (1.5-2.5 cm) wide with 5 petals. Sulfur cinquefoil fruits are achenes, about1 mm long, with a slightly winged margin [6,20,28,47,91].

There are no reports in the literature of sulfur cinquefoil growing in monospecific stands. It has been recorded at densities up to 39 flowering plants per m^2 at a site in Michigan [91], and up to 75% canopy cover on a site in Montana [69]. Density of sulfur cinquefoil in a field left fallow for 10 years in Michigan was 2.67 flowering stems per m^2 [91].

Sulfur cinquefoil forms relatively clear annual growth rings in the root xylem that can be used to estimate plant age [17].

According to Werner and Soule [91], aging of sulfur cinquefoil by counting rings in the taproot is not possible after about 6 years because the central core of the root decomposes. Estimates based, instead, on total diameter of the root ring of plants in Michigan indicate that 20-year-old plants are not unusual [91]. Using this method to estimate the age of herbaria specimens, it appears most sulfur cinquefoil plants collected in British Columbia in the last 20 years are less than 6 years old [60].

Sulfur cinquefoil has no known mycorrhizal associations [60].

RAUNKIAER [63] LIFE FORM:
Hemicryptophyte

REGENERATION PROCESSES:
Sulfur cinquefoil reproduces by seed and vegetatively by sprouting from a caudex.

Soule and Werner [79] studied reproductive effort (the proportion of aboveground biomass allocated to reproductive parts) in sulfur cinquefoil in 3 old fields in Michigan and found it to be variable among years and habitats. The average reproductive effort ranged from 16 to 28%. The 1st year of sampling indicated reproductive effort declined from the least successionally mature population to the most mature population. However, this relationship was not observed in the 2nd year of sampling [79].

Breeding system: Cross-fertilization is the most common means of fertilization in sulfur cinquefoil, but some seeds are produced by self-pollination. Sulfur cinquefoil is cross-pollinated by wind or insects [8,91].

Seed production: Werner and Soule [91] report an average of 61.5 ± 28.0 seeds per flower, 25.0 ± 10.7 flowers per stem, and 1.1 ± 0.4 stems per plant from sulfur cinquefoil studied in old fields in Michigan. From these data they calculate that a single sulfur cinquefoil plant might produce about 1,650 seeds under the site conditions of their study. In a population with 2.7 plants per m^2, about 4,400 seeds per m^2 may be produced each year [91]. On a grassland site in northwestern Montana, the proportion of sulfur cinquefoil plants producing fruit ranged from 3 to 86%, was highly variable, and was highest during years with highest precipitation. These plants produced an average of 123 seeds per fruit, when averaged over 3 years. Number of seeds per fruit was highest in the 2 wettest years, and lowest on the most xeric plot in the study [52].

Seed dispersal: When mature, most sulfur cinquefoil seed is dispersed by falling passively to the ground [91]. The importance of seed-dispersal mechanisms has not been specifically documented in sulfur cinquefoil. While grazing animals rarely eat sulfur cinquefoil, and feeding by small mammals or birds on sulfur cinquefoil plants or seeds is unknown, more research is needed to determine whether seed could be distributed by birds, small mammals, ungulates, and other grazing animals in the following ways [60]:

- In small mammal caches;
- in plant material used for nests and burrows;
- in soil trapped in ungulate hooves; and
- ingested seeds which pass through the digestive tract.

Human activities also provide several potential seed dispersal vectors [60]:

- in topsoil, gravel, and other quarried materials;
- in plant material caught in the undercarriage, doors, and wheel spokes of all-terrain vehicles, trucks, and cars;
- in soil stuck to earth-moving equipment, etc;
- in plants collected for fresh and dried floral arrangements;
- through cultivation of sulfur cinquefoil as an ornamental species; and

- in plant material cut for hay or bedding for livestock

Seed banking: In a laboratory experiment, some viable sulfur cinquefoil seeds remained after 28 months of burial at 3 inches (7 cm), suggesting the potential for forming a persistent seed bank. Several other cinquefoil species form persistent seed banks [7]. According to Rice and others [66], "sulfur cinquefoil re-establishes within 3 or 4 years following herbicide treatment. This suggests that cinquefoil seeds remain viable in the soil for more than 4 years." They do not indicate what herbicide was used or the site conditions under which this observation was made; nor do they address the possibility of sulfur cinquefoil seed dispersal from offsite sources.

The ultimate longevity of sulfur cinquefoil seeds in soil, and the relationship between soil conditions and rate of sulfur cinquefoil seed decay is yet unknown [60]. More research in this area is needed.

Germination: Baskin and Baskin [7] conducted a laboratory experiment to study germination ecology of sulfur cinquefoil. Fresh, mature sulfur cinquefoil seeds were buried and exposed to natural yearly temperature cycles. Seeds were exhumed at monthly intervals and tested in light and darkness at various 12/12 hour alternating temperature regimes. At maturity, a high percentage of sulfur cinquefoil seeds was dormant (i.e. did not germinate at any thermoperiod in either light or darkness). Some of the fresh, mature seed was conditionally dormant (2-38% germinated in light only at 59/43 and 68/50 degrees Fahrenheit (15/6 and 20/10 °C)). During summer, sulfur cinquefoil seeds after-ripened, and germination percentages and the maximum temperature at which germination occurred increased. All sulfur cinquefoil seeds were nondormant by autumn. Once dormancy is broken, seeds do no re-enter dormancy if they fail to germinate. Sulfur cinquefoil seeds did not exhibit a seasonal cycle in their germination responses. No sulfur cinquefoil germination occurred in darkness. The upper temperature limit for germination of sulfur cinquefoil seeds is around 95/68 degrees Fahrenheit (35/20 °C). Thus, buried seeds can potentially germinate during any month of the growing season, if a disturbance brings the seeds to the soil surface and moisture is not limiting [7]. In northwestern Montana, seeds collected in August germinated readily in October with warm/dark-light (55% germination) and warm-cold/dark-light (70% germination) treatments. About 5% germinated in the dark [52].

Werner and Soule [91] cite a study in which a maximum germination rate of 17.5% occurred for sulfur cinquefoil seeds after 1 month of storage in sand or 2 months in peat, under moist conditions. Germination was very low in seeds stored under dry conditions [91].

A study by Bosy and Aarssen [11] demonstrates that physical orientation of sulfur cinquefoil seed in the soil can affect germination rates. They conclude that the effects of the environment on an individual seed can depend entirely on its orientation (which may occur by chance), even within a substrate that is completely homogeneous [11].

Seedling establishment/growth: Very little information is available on seedling establishment and growth of sulfur cinquefoil. Research regarding its growth characteristics in various environments with varying degrees of plant competition is necessary to understand its potential impacts.

Recruitment of sulfur cinquefoil was low during 4 years of a study in grassland sites in northwestern Montana. Two plots averaged less than 0.5 recruits per fruiting plant, and the plot with the highest recruitment rate averaged 2 recruits per fruiting plant. The majority of plants remained in the same size class or became smaller during the study in all 4 sample populations. Mortality rates of sulfur cinquefoil in these plots ranged from 6 to 48%, and density of small sulfur cinquefoil plants remained low during the 4 years of this study. This time period coincided with 15-30% below average precipitation. Mortality rates were highest in 1999, because most of the small plants (probably recruited in 1998, a year with above average precipitation and high seedling recruitment) died. The author suggests drought combined with competition from established vegetation caused high mortality of seedlings [52].

Asexual regeneration: The usual pattern of yearly regeneration of sulfur cinquefoil is by new shoots appearing near edges of the caudex, while the old central part slowly rots away during successive growing seasons. The result is that long-lived plants are in the form of a circle of upright stems, sometimes with other plants growing in this central area. Through this means of asexual regeneration, a sulfur cinquefoil plant eventually becomes several independent closely spaced plants. Sprouting from the caudex also allows sulfur cinquefoil to survive along roadsides and other areas that are disturbed periodically, as new shoots sprout soon after established shoots are cut off [91]. This method of vegetative reproduction does not result in broad dispersal of sulfur cinquefoil plants, as the offspring grow close to the former root system of the parent plant. The importance of vegetative reproduction relative to reproduction by seed is unknown [60].

A Pacific Northwest extension publication suggests that sulfur cinquefoil can "spread by roots when they are transported by tillage or on soil-moving equipment"; and that "stems that are knocked to the ground can produce roots at the nodes" [13]. The source of this information is not specified and reference to sulfur cinquefoil reproduction by this means is not found elsewhere in the literature.

SITE CHARACTERISTICS:
Little information is available regarding site characteristics that are suitable to sulfur cinquefoil's establishment and persistence. A detailed inventory could facilitate determination of the ecological amplitude of sulfur cinquefoil and identify potential areas of impact in North America [60]. According to Rice [69,70], sulfur cinquefoil has a wide ecological amplitude, occurring in a wide range of habitat types, soil textures, aspects, and elevations.

General climate: In its native habitats in southeastern Europe and southwestern Asia, sulfur cinquefoil grows in areas with a Mediterranean climate (Schaffner and Tosevski 1994, as cited by Powell [60]). In Canada, sulfur cinquefoil is found where less than 1% of the minimum daily temperatures fall below 32 degrees Fahrenheit (0 °C) in May and less than 5% fall below 50 degrees Fahrenheit (10 °C) in July [91]. Sulfur cinquefoil flourishes in Montana's semiarid climate in areas similar to those inhabited by spotted knapweed [68,69].

Soil characteristics, soil moisture, precipitation: Sulfur cinquefoil does not seem to be limited by soil texture. In Montana, it is found on sites with all soil textures except pure silt, but grows mainly on sandy-clay loam soils [69], with dense growth reported on clay soils [68]. Sulfur cinquefoil occurred on a seasonal wetland site in Montana that had coarse textured, cobbly soils [69]. In Kansas, sulfur cinquefoil is often found in rocky or sandy soil [6]. Sulfur cinquefoil is usually found in dry soil in the northeastern U.S. [25], and along the eastern coast from Newfoundland to North Carolina [20]. According to a review by Werner and Soule [91], sulfur cinquefoil is most common on limey and stony soils in eastern North America.

In Canada, the distribution of sulfur cinquefoil corresponds to those areas with 30 to 50 inches (750-1,250 mm) mean annual precipitation [91]. In Nevada, sulfur cinquefoil occurs only in the northwestern part of the state on wet or damp soil around lakes, ponds, streams, and ditches [41]. At Dancing Prairie Preserve in northwestern Montana, where mean annual precipitation is 17 inches (438 mm), sulfur cinquefoil populations appear to be more variable and more likely to dramatically increase under favorable conditions on more xeric sites, while mesic-site populations are smaller, yet more stable [52].

Aspect, elevation, latitude/longitude: Sulfur cinquefoil is found from sea level to over 7,500 feet (2,300 m) in its native habitats in southeastern Europe and southwestern Asia (Schaffner and Tosevski 1994, as cited by Powell [60]). In Montana, sulfur cinquefoil infestations are found at all aspects and at low to mid-elevations, up to 6,580 feet (2,000 m) [70]. In California, sulfur cinquefoil is found between 500 and 5000 feet (150-1500 m) [34]. In Nevada it is found between 4,800 and 6,000 feet (1,400-1,800 m) [41]. Sulfur cinquefoil is found mainly below 50° N in Canada [91].

Evidence of disturbance: Disturbed sites are particularly susceptible to early colonization and rapid dominance by sulfur cinquefoil [70]. Sulfur cinquefoil is reported to occur in disturbed areas in California [34], Nova Scotia [72], the Great Plains [6,28], Texas [18], Montana [47], the northeastern U.S. [25], Illinois [57], the Carolinas [62], along the coast from North Carolina to Newfoundland [20], West Virginia [82], and Michigan [88]. Disturbed areas are typically described as "weedy areas," "waste places," roadsides, railroads, clearings, pastures, old fields, and gravel pits.

Sulfur cinquefoil populations in the northwestern U.S. and British Columbia are often associated with roadsides, abandoned agricultural fields, logged areas, areas with heavy livestock grazing, "waste places," and other sites associated with vegetation and/or soil disturbance [60,66,68,91]. An exclosure designed to illustrate effects of livestock and wildlife grazing by excluding elk, deer, and cattle was built in southeastern British Columbia in 1951. No sulfur cinquefoil was recorded in the area until 1991, and then it occurred only in the grazed area outside the exclosure [73]. Sulfur cinquefoil is, however, reported to rapidly invade bluebunch wheatgrass rangeland "that is in good condition and properly grazed" [37,66]; and, while it is most common and spreads more rapidly on disturbed sites on the Dancing Prairie Preserve in northwestern Montana, it is also capable of invading relatively undisturbed sites [52].

On another grassland site in western Montana, dominated by bluebunch wheatgrass and Idaho fescue on warm slopes and rough fescue on cool slopes, a study to monitor changes in species composition under the influence of cattle grazing was initiated in 1985. Canopy cover of sulfur cinquefoil increased on 2 of 3 warm slope plots and on 2 of 3 cool slope plots between 1985 and 1996. Canopy cover of sulfur cinquefoil is negatively associated with canopy cover of rough fescue and total grass. This relationship reflects the fact that sulfur cinquefoil is generally more common on more xeric sites where grass cover is less abundant. Abundance of sulfur cinquefoil also appeared to be associated with pocket gopher burrowing on 2 transects. The author suggests that, because little of the variation in sulfur cinquefoil abundance at the microplot level was explained by grass cover, other unmeasured factors, such as proximity and productivity of seed sources, may have more effect on sulfur cinquefoil cover than competition with grass. It is also not possible to determine whether the decline in grass cover is caused by grazing or by an increase in sulfur cinquefoil at this site [50].

SUCCESSIONAL STATUS:
Sulfur cinquefoil is an early successional species in North America, as indicated by its common occurrence in disturbed habitats (see Site Characteristics). Sulfur cinquefoil is often found in association with early seral stages in the Interior Douglas-fir biogeoclimatic zone in British Columbia [60]. In abandoned fields in Michigan, sulfur cinquefoil is found from the earliest stages of succession until extensive woody cover is present [79,91]. Sulfur cinquefoil was present on old fields in Michigan abandoned from cultivation 5 and 15 years previously but was not a major species on a field abandoned for only 1 year [29]. According to Beckwith [9], sulfur cinquefoil is common in the mixed herbaceous perennial stage of old-field succession which usually predominates 11 to 15 years after abandonment from grain crops and 16 to 20 years after abandonment from cultivated fields and hay fields in Michigan.

According to Rice [69,70] land managers have reported sulfur cinquefoil increases while spotted knapweed declines on numerous sites in Montana. Preferential grazing by cattle of up to 30% of spotted knapweed has also been observed, with only trace utilization of sulfur cinquefoil. This may explain, in part, why succession to sulfur cinquefoil is sometimes observed, although the possibility of species selection through herbicide use cannot be excluded (see Chemical control), since management history of these sites is not described. It is also suggested that sulfur cinquefoil competes successfully with yellow starthistle (*Centaurea solstitialis*) and leafy spurge on several sites [70]. However, there is no reference indicating the co-occurrence of sulfur cinquefoil and yellow starthistle, and only 1 example of the co-occurrence of sulfur cinquefoil with leafy spurge on 1 site in Montana [69]. There is no experimental evidence regarding the relative competitiveness of these species in the literature.

Light regime: Sulfur cinquefoil appears to be intolerant of complete shade. Sulfur cinquefoil is never associated with a 100% canopy cover of other vegetation, and is normally found in areas with less than 90% vegetative cover in southeastern Europe and southwestern Asia (Schaffner and Tosevski 1994, as cited by Powell [60]). In Michigan, sulfur cinquefoil is found along wood margins, but not under forest canopy [91]. Sulfur cinquefoil occurred in 3 old fields in Michigan which received 51 to 84% of full sunlight. The lowest light level (51%) was in a shrubby habitat dominated by staghorn sumac [79]. Shading from a dense overstory prevents establishment of sulfur cinquefoil in mature forests in western Montana, but sulfur cinquefoil can successfully occupy areas below natural gaps in the forest canopy [70].

SEASONAL DEVELOPMENT:
Research is needed on the phenology of sulfur cinquefoil in different areas in which it occurs.

Flowering dates given for sulfur cinquefoil by region are:

State/region	Flowering dates	References
Adirondacks	June 19 through July; immature fruit August 4	[45]
Carolinas	April-July	[62]
eastern seaboard, from Newfoundland to North Carolina	April to September	[20]
Great Plains	May to July	[28]
Illinois	May to July	[57]
Kansas	May -June (July)	[6]
Nevada	June to July	[41]
Northeast	June thru August	[25]
West Virginia	May-August	[82]
Nova Scotia	June 20 to July	[72]

Sulfur cinquefoil plants germinating in the spring establish woody taproots in their 1st growing season [60,91]. In Montana, sulfur cinquefoil is one of the 1st plants to emerge in spring. It begins flowering in May and will continue to flower throughout the summer if conditions are favorable [66]. It is one of the fastest plants to green up in fall in response to late summer/early fall rains, and continues to grow until freezing temperatures are sustained [69]. The following table provides timing of growth stages observed for sulfur cinquefoil in Montana [69]:

Date	Growth stage
early/mid March	first basal leaves emerge
April	basal rosettes fully formed
May	bolt
late May/early June	bud stage
June	bloom
July	seed set
late July/early August	seed dispersal begins
August	leaf senescence
September/October	fall greenup with new basal leaves
late October	growth stops after extended freeze

In Michigan in 1975, sulfur cinquefoil began flowering about 1 June, with the majority of the buds in anthesis about 21 June. On any individual plant, flowers were produced for many weeks, the earliest forming mature seed heads at the same time the later buds are coming into flower. Flowering continued until about 7 August, at which time 59.8% of the flower heads had produced mature seeds [91].

FIRE ECOLOGY

SPECIES: Potentilla recta

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:
Fire adaptations: There is little information available regarding sulfur cinquefoil's adaptations to fire. The survival of plant parts after fire depends on depth of burial and fire severity. Perennating buds in the caudex of sulfur cinquefoil can survive fire if they are not exposed to lethal temperatures. The available literature does not specify the location of sulfur cinquefoil's perennating buds in relation to the soil surface.

Sulfur cinquefoil is likely to resprout from the caudex following fire, and/or plants may respond by developing heavier rootstocks, as was observed with plants whose topgrowth was removed by mowing in Michigan [91]. Heat tolerance of sulfur cinquefoil's perennating tissues is unknown.

Heat tolerance of sulfur cinquefoil seeds is also unknown; buried seeds may survive fires of low severity. Postfire conditions including decreased aboveground competition, increased light at the soil surface, and enhanced nutrient availability are favorable for sulfur cinquefoil establishment from seed. Plants may re-establish either from on-site seed or from seed dispersed into a burned area following fire.

Fire regimes: Sulfur cinquefoil occurs in ecosystems with historic fire regimes of varied frequency and severity, from frequent, low-severity fires in ponderosa pine ecosystems, to less frequent and more severe fires in bunchgrass ecosystems, to frequent and severe fires in plains and prairie grassland ecosystems. Many of these historic fire regimes have been dramatically altered. Sulfur cinquefoil did not occur or was not widespread in these communities when historic fire regimes were functioning, but established after habitat alteration and fire exclusion began. It is unclear how historic fire regimes might affect sulfur cinquefoil populations in many situations, and it is unclear how the presence of sulfur cinquefoil in native ecosystems might affect fire regimes.

On fescue-wheatgrass-needlegrass (*Festuca* spp.-*Agropyron* spp.-*Hesperostipa* spp.) habitats of the Tobacco Plains in northwestern Montana, fires caused by lightning and ignited by Native Americans played an important role in structuring vegetation [42]. Most presettlement fires occurred during the summer and early fall [31]. In this area, on The Nature Conservancy's Dancing Prairie Preserve, sulfur cinquefoil has become a major component in portions of the grassland. Experiments with prescribed fire indicate that sulfur cinquefoil had a more positive response to fall burning than to spring burning. In this case, fall fires may favor sulfur cinquefoil and damage desirable native species. This may be especially true after a long period of fire exclusion leading to a build-up of fuels and increased fire severity [53]. In other ecosystems, such as the C_4-dominated grasslands of North America, early- and late-spring burns can result in high mortality of early-germinating, nonnative species, with little damage to native flora [78].

There is no evidence in the literature that sulfur cinquefoil alters historic fire regimes in ecosystems it invades. In general, in ecosystems where sulfur cinquefoil replaces plants similar to itself (in terms of fuel characteristics), it may alter fire intensity or slightly modify an existing fire regime. However, if sulfur cinquefoil is qualitatively unique to the invaded ecosystem, it may have the potential to alter the fire regime [16].

The following table provides fire return intervals for important plant communities and ecosystems in which sulfur cinquefoil may occur. Find further fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)

grand fir	*Abies grandis*	35-200 [2]
bluestem prairie	*Andropogon gerardii* var. *gerardii-Schizachyrium scoparium*	< 10 [43,59]
Nebraska sandhills prairie	*A. g.* var. *paucipilus-S. s.*	< 10
sagebrush steppe	*Artemisia tridentata/Pseudoroegneria spicata*	20-70 [59]
plains grasslands	*Bouteloua* spp.	< 35 [59,93]
blue grama-needle-and-thread grass-western wheatgrass	*B. gracilis-Hesperostipa comata-Pascopyrum smithii*	< 35 [59,74,93]
blue grama-buffalo grass	*B. gracilis-Buchloe dactyloides*	< 35 [59,93]
California steppe	*Festuca-Danthonia* spp.	< 35 [59,81]
western juniper	*Juniperus occidentalis*	20-70
Rocky Mountain juniper	*J. scopulorum*	< 35
cedar glades	*J. virginiana*	3-7 [59]
western larch	*Larix occidentalis*	25-100 [2]
wheatgrass plains grasslands	*Pascopyrum smithii*	< 5-47+ [59,61,93]
Great Lakes spruce-fir	*Picea-Abies* spp.	35 to > 200 [19]
Engelmann spruce-subalpine fir	*P. engelmannii-A. lasiocarpa*	35 to > 200 [2]
jack pine	*Pinus banksiana*	<35 to 200 [19]
western white pine*	*P. monticola*	50-200
Pacific ponderosa pine*	*P. ponderosa* var. *ponderosa*	1-47 [2]
interior ponderosa pine*	*P. ponderosa* var. *scopulorum*	2-30 [2,5,49]
red pine (Great Lakes region)	*P. resinosa*	10-200 (10**) [19,23]
red-white-jack pine*	*P. resinosa-P. strobus-P. banksiana*	10-300 [19,33]
eastern white pine	*P. strobus*	35-200
Virginia pine	*P. virginiana*	10 to < 35
Virginia pine-oak	*P. virginiana-Quercus* spp.	10 to < 35 [89]
quaking aspen (west of the Great Plains)	*Populus tremuloides*	7-120 [2,30,56]
mountain grasslands	*Pseudoroegneria spicata*	3-40 (10**) [1,2]
Rocky Mountain Douglas-fir*	*Pseudotsuga menziesii* var. *glauca*	25-100 [2,3,4]
coastal Douglas-fir*	*P. menziesii* var. *menziesii*	40-240 [2,58,71]
oak-hickory	*Quercus-Carya* spp.	< 35 [89]
oak-juniper woodland (Southwest)	*Quercus-Juniperus* spp.	< 35 to < 200 [59]
northeastern oak-pine	*Quercus-Pinus* spp.	10 to < 35
northern pin oak	*Q. ellipsoidalis*	< 35
bur oak	*Q. macrocarpa*	< 10 [89]
oak savanna	*Q. macrocarpa/Andropogon gerardii-Schizachyrium scoparium*	2-14 [59,89]
northern red oak	*Q. rubra*	10 to < 35 [89]
little bluestem-grama prairie	*S. scoparium-Bouteloua* spp.	< 35 [59]
western redcedar-western hemlock	*Thuja plicata-Tsuga heterophylla*	> 200 [2]

elm-ash-cottonwood	*Ulmus-Fraxinus-Populus* spp.	< 35 to 200 [19,89]

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

POSTFIRE REGENERATION STRATEGY [80]:
Caudex/herbaceous root crown, growing points in soil
Ground residual colonizer (on-site, initial community)
Initial off-site colonizer (off-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: Potentilla recta

IMMEDIATE FIRE EFFECT ON PLANT:
There is little published information available regarding effects of fire on sulfur cinquefoil. The survival of plant parts after fire depends on their depth of burial and fire severity. Large sulfur cinquefoil plants are top-killed by fire, and perennating buds in the caudex can survive fire if they are not exposed to lethal temperatures [53]. The available literature does not specify the location of sulfur cinquefoil's perennating buds in relation to the soil surface.

At Dancing Prairie Preserve in northwestern Montana, neither fall nor spring burning resulted in mortality of large (≥5 leaves and a woody caudex) sulfur cinquefoil plants. Fire had a significant ($p<0.05$) negative effect on density of small (1-4 leaves without a well-developed caudex) sulfur cinquefoil plants immediately after burning; however this effect was detectable for only 1 year after fire [53].

Heat tolerance of sulfur cinquefoil seeds is unknown. Results from Dancing Prairie Preserve indicate recruitment of sulfur cinquefoil occurred in burn plots the 1st year following both spring and fall burning. More recruitment was observed in fall burn plots, which had higher fire severity [53]. If no sulfur cinquefoil seed was dispersed into the burned area from offsite sources, it may be assumed that sulfur cinquefoil seeds can survive this type of grassland fire.

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
Density of small sulfur cinquefoil plants declined in both burn and control plots the 1st year following burn treatments on Dancing Prairie Preserve, and was probably caused by 51% below average precipitation the previous summer. Mean density of small sulfur cinquefoil plants declined by 47% in control plots, by 42% in spring burn plots, and by 12% in fall burn plots. Smaller declines in density of small sulfur cinquefoil plants in burn versus control plots may indicate that fire has a positive effect on germination and recruitment of sulfur cinquefoil, especially following fall burns [53].

PLANT RESPONSE TO FIRE:
There is little information available regarding sulfur cinquefoil's response to fire. Sulfur cinquefoil's response to fire probably depends on fire severity, plant phenological stage at the time of burning, depth of burial of perennating tissues and seeds, and the composition of the prefire plant community. Postfire conditions including decreased aboveground competition, increased light at the soil surface, and enhanced nutrient availability favor growth of surviving sulfur cinquefoil plants and establishment of sulfur cinquefoil from seed. Plants may re-

establish either from on-site seed or from seed dispersed into a burned area following fire. Sulfur cinquefoil resprouts from the caudex and develops heavier rootstocks when topgrowth is removed by mowing [91]. Sulfur cinquefoil plants may react in a similar way when topgrowth is removed by fire as long as perennating tissues survive.

At Dancing Prairie Preserve, density of small sulfur cinquefoil plants declined less in burn plots compared to control plots during the year following burn treatments, indicating that fire enhanced survival of new recruits. During the 2nd year following burn treatments, the number of small plants continued to decline, while the number of large plants increased, probably indicating growth into the larger size classes rather than attrition. There was a tendency for the number of large plants to increase in burn plots, although the difference was not statistically significant ($p<0.05$) [53].

Results from Dancing Prairie [53] also suggest that prescribed fire can enhance germination of sulfur cinquefoil. However, survival of seedlings depends on sufficient moisture. In semiarid grasslands, moisture is often lacking, and may not, therefore, result in population growth of sulfur cinquefoil. Burning will lead to an increase in mature plants only if the climate in subsequent years is conducive to survival [53].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Fire can, but will not always, cause an increase in population growth of nonnative invasive plants in semiarid regions. "The vagaries of climate will likely play a major role in determining whether prescribed fire will do more harm than good" [53]. Season of burning and timing of burning within the season also appear to affect response of sulfur cinquefoil to fire in the fescue-wheatgrass-needlegrass grasslands at Dancing Prairie Preserve in northwestern Montana [53].

Response of sulfur cinquefoil to fire differed between spring and fall burns at Dancing Prairie Preserve. Density of small plants increased more in fall-burn plots the 1st year after burning. However, density of small plants was greater in spring-burn plots by the final year of the study (5 years after fire). Observations of postfire residual litter indicate that fire severity was greater for fall burns, possibly resulting in 'better' physical conditions for seedling establishment (less litter, more light, less competition). Plant response to season of fire may depend on germination requirements. Sulfur cinquefoil seeds germinate without stratification, suggesting that many seeds may germinate in fall if conditions are suitable. In this study, sulfur cinquefoil had a more positive response to fall burning than to spring burning [53].

Timing of fire within the season is also important to plant response. "Relatively cool" fire prior to germination may stimulate seeds to germinate (by breaking physical dormancy or providing important nutrients) while fire after germination could cause high mortality of seedlings [53]. A large proportion of sulfur cinquefoil seeds will germinate in fall without cold treatment [52], so a fall burn could cause high mortality of young seedlings. At Dancing Prairie, it appears that a large number of sulfur cinquefoil seeds had not germinated by mid-October in 1996 when the fall burn was conducted. Further research on the relationship between germination requirements and timing of burns could lead to fire prescriptions that minimize the increase of invasive plants [53].

Effects of season of burning on sulfur cinquefoil may also depend on composition of the plant community. In C_3-dominated grasslands such as those at Dancing Prairie, dormant season and late fall burns are more likely to harm nonnative, invasive plant populations without damaging native species, while late-spring and early-fall burns are more detrimental to native species. However, early and late spring burns in C_4 dominated grasslands, such as those of central North America, result in high mortality of early-germinating C_3 nonnative plants with little damage to the native flora [78] and may therefore be preferable to growing- or late-season burns [53].

The Research Project Summary Vegetation response to restoration treatments in ponderosa pine-Douglas-fir forests of western Montana provides information on prescribed fire and postfire response of plant community species including sulfur cinquefoil.

FIRE MANAGEMENT CONSIDERATIONS:
Fire as a control agent: Burning may not be recommended for control of sulfur cinquefoil, because perennial

roots are likely to survive and resprout following fire.

Prescribed fire may be used as a management tool on some sites to control woody plants, restore historic fire regimes, and promote desirable species [53]. The disturbance created by fire can, however, favor invasive perennial forbs (e.g. [15,36,54]). Season of burning and other management activities (e.g. herbicide treatments, livestock and wildlife use) are important factors to consider when prescribing fire for natural area restoration where nonnative invasive plants are present [53].

Understanding the regeneration niche of invasive and desirable plants and selecting the best season for burning can help reduce the chance of problems. Practices that reduce the target plant's seed bank can reduce the chance of increased recruitment following fire. In some cases prescribed fire should be delayed until nonnative invasive plants have been controlled [53].

On The Nature Conservancy's Dancing Prairie Preserve in northwestern Montana, dormant-season fire can inhibit ponderosa pine invasion, reduce litter, invigorate native bunchgrasses, and enhance recruitment of native forbs including the federally-listed, threatened Spalding's silene (*Silene spaldingii*) [51]. Spalding's silene has a more positive response to spring burns compared to fall burns, while sulfur cinquefoil had a more positive response to fall burns. Additionally, more severe fall burns can be detrimental to rough fescue, the dominant native grass at the preserve, especially if there have been many years of fire exclusion leading to build-up of fuels and more severe fire effects. Prescribed burning conducted in the spring would be more beneficial than fall burning at this site [53].

When herbicide (e.g. picloram) is applied prior to prescribed burning, its residual activity may be reduced as a result of soil heating during and following fire. Sulfur cinquefoil seeds began germinating 1 to 3 years earlier in herbicide/burn plots compared to plots with only herbicide. There may be little benefit from residual activity of such herbicides where annual or biennial burning is practiced, as on many tallgrass prairies [53]. Alternatively, efficacy of herbicide on mature target plants may be enhanced by burning prior to herbicide application. Further research is needed on effects of combining herbicide treatments and prescribed fire.

Postfire colonization potential: Sulfur cinquefoil may establish after fire either by seed imported to the site or by soil-stored seed. More information is needed regarding sulfur cinquefoil seedling establishment and growth with and without fire.

Preventing postfire establishment and spread: The USDA Forest Service's "Guide to Noxious Weed Prevention Practices" [85] provides several fire management considerations for weed prevention in general that apply to sulfur cinquefoil.

Preventing invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. This can be accomplished through early detection and eradication by careful monitoring, and by limiting invasive plant seed dispersal into burned areas by [26,85]:

- re-establishing vegetation on bare ground as soon as possible
- using only certified weed-free seed mixes when revegetation is necessary
- cleaning equipment and vehicles prior to entering burned areas
- regulating or preventing human and livestock entry into burned areas until desirable site vegetation has recovered sufficiently to resist invasion by undesirable vegetation
- detecting weeds early and eradicating before vegetative spread and/or seed dispersal
- eradicating small patches and containing or controlling large infestations within or adjacent to the burned area

In general, early detection is critical for preventing establishment of large populations of invasive plants. Monitoring in spring, summer, and fall is imperative. Managers should eradicate established sulfur cinquefoil plants and small patches adjacent to burned areas to prevent or limit seed dispersal into the site [26,85].

The need for revegetation after fire can be based on the degree of desirable vegetation displaced by invasive plants prior to burning and on postfire survival of desirable vegetation. Revegetation necessity can also be related to invasive plant survival as viable seeds, root crowns, or rhizomes capable of reproduction. In general, postfire revegetation should be considered when desirable vegetation cover is less than about 30% [26].

When prefire cover of sulfur cinquefoil is absent to low, and prefire cover of desirable vegetation is high, revegetation is probably not necessary after low- and medium-severity burns. After a high-severity burn on a site in this condition, revegetation may be necessary (depending on postfire survival of desirable species), and intensive monitoring for invasive plant establishment is necessary to detect and eradicate newly established invasives before they spread [26].

When prefire cover of sulfur cinquefoil is moderate (20-79%) to high (80-100%), revegetation may be necessary after fire of any severity if cover of desired vegetation is less than about 30%. Intensive weed management is also recommended, especially after fires of moderate to high severity [26].

Fall dormant broadcast seeding into ash will cover and retain seeds. If there is insufficient ash, seedbed preparation may be necessary. A seed mix should contain quick-establishing grasses and forbs (exclude forbs if broadleaf herbicides are anticipated) that can effectively occupy available niches. Managers can enhance the success of revegetation (natural or artificial) by excluding livestock until vegetation is well established (at least 2 growing seasons) [26].

When planning a prescribed burn, managers should preinventory the project area and evaluate cover and phenology of any sulfur cinquefoil and other invasive plants present on or adjacent to the site, and avoid ignition and burning in areas at high risk for sulfur cinquefoil establishment or spread due to fire effects. Managers should also avoid creating soil conditions that promote weed germination and establishment. Weed status and risks must be discussed in burn rehabilitation plans. Also, wildfire managers might consider including weed prevention education and providing weed identification aids during fire training; avoiding known weed infestations when locating fire lines; monitoring camps, staging areas, helibases, etc., to be sure they are kept weed free; taking care that equipment is weed free; incorporating weed prevention into fire rehabilitation plans; and acquiring restoration funding. Additional guidelines and specific recommendations and requirements are available [85].

MANAGEMENT CONSIDERATIONS

SPECIES: Potentilla recta

- IMPORTANCE TO LIVESTOCK AND WILDLIFE
- OTHER USES
- IMPACTS AND CONTROL

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
There is little information on use of sulfur cinquefoil by grazing animals, although it is thought to be avoided by most grazing animals [70]. Utilization of sulfur cinquefoil by cattle was less than 1% on 98% of 85 sites studied in Montana; and 1-5% on the remaining 2% of these sites. This trace grazing usually consisted of removal of buds and flower tops from a small number of plants. Intensive grazing systems can increase utilization to above 5%, but sulfur cinquefoil appears to be one of the last plants selected [69,70].

Other studies indicate that cinquefoil species generally make up a very small percentage of the diets of grazing animals. In the lower Rocky Mountain Trench of British Columbia, cattle, elk and mule deer diets averaged 0.4, 0.2, and 0.3%, respectively, cinquefoil species (of which sulfur cinquefoil was a constituent) [91]. Campbell and Johnson [14] found that cinquefoil species comprised 2.5, 0.3, 1.3, and 0.2% of winter, spring, summer, and fall diets, respectively, of mule deer in Washington. Winter elk diets in New Mexico contained 1.1% cinquefoil species [75].

Feeding by small mammals or birds on sulfur cinquefoil plants or seeds is unknown [60].

Palatability/nutritional value: According to reviews by Powell [60] and Werner and Soule [91], sulfur cinquefoil has a tannin content of 17-22% dry weight that likely lowers its palatability relative to many other forage and browse species. Even when forage and browse choice is limited, cattle have been reported to graze the bitter-flavored spotted knapweed preferentially over sulfur cinquefoil [66]. There are no reports of sulfur cinquefoil toxicity to animals that consume it.

Cover value: No information

OTHER USES:
A review by Powell [60] indicates that sulfur cinquefoil may have been used as a folk medicine in eastern Europe. The possible medicinal value, however, has not been thoroughly studied [60].

Because of its perennial nature and showy flowers, sulfur cinquefoil is also used in horticulture [60].

IMPACTS AND CONTROL:
Impacts: Explicit in the definition of sulfur cinquefoil as a problem species is the assumption that it displaces other plant species and the myriad organisms that depend on these plant communities, as well as the negative economic consequences for industries based on these natural resources. Sulfur cinquefoil may have harmful impacts on native flora and fauna, however more research is needed to clarify the extent of these impacts [60]. Untested hypotheses and unsubstantiated claims can be perpetuated in the literature until they become widely accepted, without the benefit of experimental analysis or peer review. A well-documented example of this occurred with purple loosestrife [32].

The following information on impacts of sulfur cinquefoil, its ability to outcompete native and other nonnative plants, and its rapid rate of expansion are commonly found in agricultural extension and gray literature though they are largely untested. To better define its potential impacts, research is needed on the competitiveness of sulfur cinquefoil relative to other plant species, its rate of expansion, its persistence at various seral stages in different ecosystems, its ecological amplitude, and its influence on the dynamics of various ecosystems [60].

There are no specific data on the relative competitiveness of sulfur cinquefoil. Its perennial nature and large root reserves likely give it a competitive advantage in open-canopied situations, but the relative advantage of these attributes remain unquantified [60]. According to Rice and others [66,68] sulfur cinquefoil displaces native plant species in undisturbed habitats, reduces grass production, and may alter the functioning of ecosystems by lowering biodiversity, although this is not documented quantitatively.

Based on canopy cover estimates of sulfur cinquefoil at 85 sites in western Montana, Rice [70] concludes that "sulfur cinquefoil often becomes a significant component of the plant community, and has proceeded to dominance on many sites" [69]. At 75% of the 85 sampled sites, sulfur cinquefoil canopy cover exceeded 5% of the plant cover; on 50% of the sites, sulfur cinquefoil canopy cover exceeded 15%; on 14% of the sites, sulfur cinquefoil canopy cover was 50% or more; and on 1 site, sulfur cinquefoil canopy cover was 75%. On most sites sulfur cinquefoil canopy cover ranged from 5 to 15% [69]. While Rice [69] suggests that canopy cover is a useful measure of the severity of a weed infestation and the competitive ability a particular plant, Lesica [50] indicates that canopy cover estimates are subjective and can be dependent on yearly climatic fluctuations, and not, therefore, very useful for monitoring trends in plant communities.

Rice also suggests that sulfur cinquefoil competes well with other nonnative, invasive species such as yellow starthistle, leafy spurge, and spotted knapweed, although no quantitative evidence is given [69,70]. Land managers in Montana indicate that sulfur cinquefoil displaces spotted knapweed on several sites [37,69]. The management history of these sites is unknown, and may influence the relationship between sulfur cinquefoil and spotted knapweed. For example, if clopyralid is used to control spotted knapweed, sulfur cinquefoil would be favored since sulfur cinquefoil is not sensitive to clopyralid [46,70]. Similarly, sulfur cinquefoil may be displacing diffuse knapweed on sites in British Columbia where knapweed vigor is reduced by introduced biological control agents [60].

In 1981, Forcella and Harvey [22] plotted the number of counties reporting the presence of each of 100 nonnative plant species in Washington, Oregon, Idaho, Montana, and Wyoming over time and described 3 patterns of infestation. They described infestation by sulfur cinquefoil as following an "exponential pattern." The distribution of sulfur cinquefoil was rapidly increasing as of 1980, and they predicted that it would become a problem in western Montana, eastern Washington and central Idaho "at some later date" [22]. According to Rice [70] "sulfur cinquefoil is rapidly increasing its geographic distribution. The number of new colonies is increasing exponentially. Many of these infestations are reaching environmentally severe sizes and densities." These assessments, however, remain neither confirmed nor denied by experimental data [60].

While it has been suggested that sulfur cinquefoil infestations can expand rapidly, and large infestations are not uncommon, the majority of colonies of sulfur cinquefoil observed in western Montana were small, with half of them less than 10 acres (4ha) [69,70].

The influence and interaction of sulfur cinquefoil with chemical and biological soil processes are also largely unknown. As a pioneer species on disturbed soil, it may help to bind soil and prevent erosion [60,91]. The breakdown of annual growth and root exudates likely releases tannins into the soil, but their influence on soil ecology and water quality have not been examined. Sulfur cinquefoil is not known to be allelopathic, and its interactions with soil biota also remain unquantified [60].

Control: Correct identification is an important first step in controlling sulfur cinquefoil, as it may be easily mistaken for native cinquefoils (see General Botanical Characteristics).

Prevention of sulfur cinquefoil establishment by maintaining native plant communities in an undisturbed condition is the most effective control strategy. Monitoring, early detection and eradication of newly established plants before seeds are produced and populations expand is more efficient and effective than laboring to control established infestations. Individual plants and small patches of sulfur cinquefoil can be eliminated by hand-pulling or digging, or by spot spraying of herbicides. The root crown (upper portion of the root system) must be removed or killed so that plants cannot resprout.

Because sulfur cinquefoil seeds may remain viable in the soil for 3 years or more [66], treated sites must be monitored annually for newly established sulfur cinquefoil plants [70].

Because sulfur cinquefoil occurs and is competitive with several other invasive species [69], management to control it and/or other species must consider the possibility of succession to other undesirable species when plants are removed.

Prevention: Preventing sulfur cinquefoil infestations is the most time- and cost-effective management approach. This is accomplished by maintaining desirable plant communities (by limiting livestock grazing, minimizing soil disturbance, and seeding disturbed sites with desirable species), preventing sulfur cinquefoil seeds from entering uninfested areas, and careful monitoring for and early eradication of newly established sulfur cinquefoil plants. This is especially important where sulfur cinquefoil is common in areas around the management site, especially along roads, trails, and rivers.

Prevent sulfur cinquefoil seeds from entering uninfested areas as follows:

- Check and clean equipment before moving it into infested areas or before bringing it from infested areas.

- When moving livestock from infested to uninfested areas, hold them in corrals or small pastures until viable seeds have had time to pass through the digestive tract (6 days for cattle, 11 days for sheep).
- Monitor for sulfur cinquefoil seedling establishment in livestock holding areas and areas where dirt has been imported [48].
- Avoid purchasing feed or seed that could be contaminated with weed seeds. Viable sulfur cinquefoil seeds may even be present in feed pellets.
- Treat road construction projects as 10- to 20-year biological projects rather than 1- to 2-year engineering projects, with biologists and resource managers overseeing road construction and restoration. Projects should not be considered complete until native vegetation is fully established. Topsoil removed during construction can be redeposited in roadside ditches, and roadsides reseeded with native species. Roadsides should then be regularly monitored and actively managed for control and eradication of nonnative species [84].

Integrated management: While there is no specific information on integrated management of sulfur cinquefoil, a combination of control methods is often necessary to eradicate or successfully contain infestations of nonnative invasive plants. Managers are encouraged to integrate different control methods that can complement one another in a given situation. Integrated management includes considerations of not only killing the target plant, but also of establishing desirable species and discouraging nonnative, invasive species over the long-term.

Physical/mechanical: Hand-digging or hand-pulling sulfur cinquefoil plants can be effective in small infestations, but may be impractical for large infestations, since the entire root crown must be removed in order to kill the plant [60,70]. Annual monitoring must be conducted to locate new plants that may establish from the soil seed bank or from seed dispersed from off-site sources.

Mowing is not effective for controlling sulfur cinquefoil. It responds by developing heavier, horizontally spreading roots and increasing vegetation near ground level [70,91]. In Michigan, the mean dry weight of roots was much greater in plants growing in a mown strip (4.2 g per plant) than from plants in the adjacent undisturbed field (2.0 g per plant) [91].

Sulfur cinquefoil can be controlled by plowing and planting to a clean-cultivated crop [91]. In a sulfur cinquefoil-infested field in Michigan plowed in May, seedlings of sulfur cinquefoil were numerous by mid-June, as well as plants emerging from old rootstock [91]. Discing and reseeding to grass at a site in British Columbia resulted in complete control of sulfur cinquefoil. This, of course, cannot be applied over grassland and forest ecosystems that are managed in their natural state [60].

Fire: See Fire Management Considerations.

Biological: Biological control of invasive species has a long history, and there are many important considerations to be made before the implementation of a biological control program. The reader is referred to other sources (e.g. [65,92]) and the Weed Control Methods Handbook [83] for background information on biological control. Additionally, Cornell University, Texas A & M University, and NAPIS websites offer information on biological control.

There are currently no biological control agents available for sulfur cinquefoil, although a number of insects and fungi are associated with sulfur cinquefoil. A field survey in Eurasia identified 26 phytophagous insect species associated with sulfur cinquefoil in its native range [76]. A survey in the northeastern U.S. identified 47 species of phytophagous insects and pollinators on sulfur cinquefoil; among them are the strawberry root weevil and the strawberry aphid [8]. A rust fungus was found on sulfur cinquefoil at 79% of sampled sites in Montana. Root and crown boring insects were also collected from sulfur cinquefoil plants on numerous sites, and 6 species were isolated from these collections. Three of the identified species are known to be pests on strawberry (*Fragaria* spp.) [69]. The rust fungus is also known to occur on several of the sulfur cinquefoil populations in British

Columbia. Three plant diseases have also been associated with sulfur cinquefoil populations in British Columbia [60].

A biological control program using insects against sulfur cinquefoil would be difficult due to the close genetic relationship between strawberries and cinquefoils, and probable attractiveness of strawberry to phytophagous insects that attack *Potentilla* [8]. Based on this close relationship, Batra [8] concludes that initiation of a biological control program for sulfur cinquefoil is not highly recommended. Additionally, a potential biocontrol agent must also be benign to (or incapable of occupying the habitats of) about 70 species of *Potentilla* with more than 80 subspecies and varieties that are found in North America [60]. Given the close relationship between sulfur cinquefoil and other *Potentilla* and *Fragaria* species, and the large number of native and introduced plants that must be screened, the search for a suitable biological control could be the longest and most costly in the history of North America [60].

Nonetheless, by 1996, 2 potential biological control agents were targeted for screening, a root moth (*Tinthia myrmosaeformis*) and a seed head weevil (*Anthonomus rubripes*) [67]. Field releases of any such insects would occur a decade or more in the future [70].

Sulfur cinquefoil is unpalatable to most livestock. Goats are the only animals that have been reported to select for sulfur cinquefoil [70]. Intensive grazing systems can increase sulfur cinquefoil utilization to about 5%, but sulfur cinquefoil appears to be one of the last plants selected [69,70].

Chemical: Herbicides are effective in gaining initial control of a new invasion (of small size) or a severe infestation, but are rarely a complete or long-term solution to invasive species management [12]. Herbicides are more effective on large infestations when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations. Control with herbicides is temporary, as it does not change conditions that allow infestations to occur (e.g. [95]). See the Weed Control Methods Handbook [83] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals.

Dicamba and clopyralid do not effectively control sulfur cinquefoil [66,70]. Picloram (applied in fall or spring), 2,4-D ester (applied in spring at rosette through bud stage), or a mix of dicamba and 2,4-D amine (applied at the rosette stage), are each effective at controlling sulfur cinquefoil. 2,4-D ester is suggested where potential water contamination is a consideration. On dryland sites, picloram may be preferred because its residual activity can suppress re-establishment from seeds in the soil seed bank [70], but it is still necessary to conduct appraisal surveys of treated sites in subsequent years, and plan systematic retreatments if eradication is the management goal [69].

Because sulfur cinquefoil is not sensitive to clopyralid [46], application of clopyralid to mixed stands of sulfur cinquefoil and spotted knapweed will depress the spotted knapweed without harming sulfur cinquefoil, thereby giving sulfur cinquefoil the competitive advantage [70].

Cultural: Because sulfur cinquefoil is intolerant of complete shade, land management practices that allow other vegetation to increase in cover, and therefore contribute to a concomitant decline in sulfur cinquefoil, should be promoted. Grazing should be managed with appropriate timing, intensity, frequency, and duration to leave adequate desirable vegetation. Soils disturbed by logging, construction, or other management activities should be revegetated as soon as possible with desirable species [60].

Potentilla recta: References

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