SPECIES: Cytisus scoparius, C. striatus

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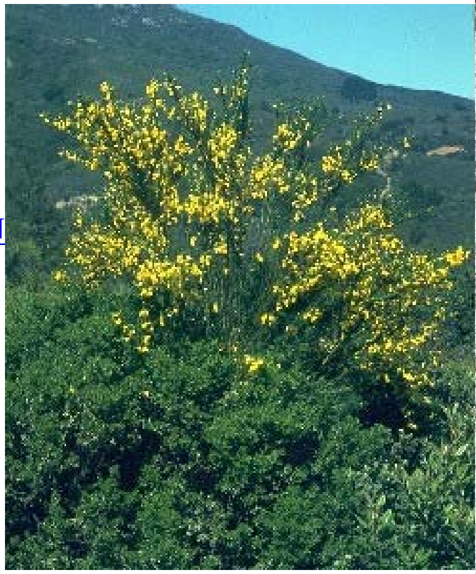
INTRODUCTORY



Scotch broom

© Br. Alfred Brousseau, Saint Mary's College

Portuguese broom

© 2005 Michael L. Charters, Sierra Madre, CA.

AUTHORSHIP AND CITATION:
Zouhar, Kris. 2005. Cytisus scoparius, C. striatus. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2007, September 24].

FEIS ABBREVIATION:
CYTSCO
CYTSTR
CYTSPP

SYNONYMS:
None

NRCS PLANT CODE [141]:
CYSC4
CYST7

COMMON NAMES:
Scotch broom
Portuguese broom
English broom
scotchbroom
striated broom

TAXONOMY:
The scientific name for Scotch broom is *Cytisus scoparius* (L.) Link [48,55,57,63,105,112,126,132,147,154,160] and for Portuguese broom is *C. striatus* (Hill) Rothm. [55,63,132]. Both are in the pea family (Fabaceae).

In North America, there are 2 varieties of Scotch broom, distinguished by their flower color: *C. scoparius* var. *scoparius* and *C. scoparius* var. *andreanus*
(Puiss.) Dipp. The former is the more widely distributed variety, and the latter occurs only in California [63]. This review does not distinguish between these varieties. No infrataxa are described for Portuguese broom.

There are no known naturally occurring hybrids of either Scotch broom or Portuguese broom. There are, however, a number of ornamental hybrids. Some hybrids have escaped cultivation in Australia, although none are thought to be invasive [9,60,98].

LIFE FORM:
Shrub

FEDERAL LEGAL STATUS:
None

OTHER STATUS:
Scotch broom is classified as a noxious weed in Hawaii, Idaho, and Oregon, as a List C noxious weed by the California Department of Food and Agriculture, and as a Category B nonnative weed in Washington. Scotch broom is classified as a "Category 3," widespread nonnative species by the USDA, Forest Service, Eastern Region [140]. Portuguese broom is classified as a Category B noxious weed in Oregon [142]. See the Invaders database for more information. Both species occur and are considered noxious in Australia [60].

DISTRIBUTION AND OCCURRENCE

SPECIES: Cytisus scoparius, C. striatus

GENERAL DISTRIBUTION:
The following information on the general distribution of Scotch and Portuguese broom is based primarily on literature reviews ([17,35,89,98,149]), unless otherwise cited.

Scotch broom is native to northern Africa and parts of Europe, ranging from northern Africa north to Sweden and the British Isles and east to Ukraine. Throughout its native range it is invasive in neglected areas and encroaches onto poorer pastures in Spain and Portugal. It is also abundant on the hillsides around Rome. Eastward in Europe it is not found beyond Poland and Hungary. In the British Isles, it is a weed of forests and hill grazing land.

Scotch broom has been introduced to many parts of the world as an ornamental (e.g. Canada, Chile, India, Iran, Australia, New Zealand, South Africa, and the United States). It is a major weed problem in Australia and New Zealand. In North America, Scotch broom was introduced to Virginia in the early 1800s for use as fodder for domestic sheep. It was considered invasive in this area by 1860 [71]. Scotch broom was introduced to California as an ornamental in the 1850s, was widely used for roadside erosion control in the early 1900s, and was recognized as a problem in California in the 1930s [75]. It was introduced to Vancouver Island in 1850 as an ornamental; and from 3 surviving plants, it spread over most of Vancouver Island over the next century and a half [101]. Deliberate plantings of Scotch broom by the British Columbia Ministry of Highways have accelerated the spread of Scotch broom during the past 50 years.

The current North American distribution of Scotch broom is along the Atlantic coast from Nova Scotia to Massachusetts, Delaware, Virginia, and Georgia; along the Pacific coast from British Columbia to central California; and inland to Idaho, Montana, and Utah. It also has scattered occurrences in several inland states in the eastern United States, and occurs in Hawaii. The worst infestations of Scotch broom occur from British Columbia to central California, from the coast to the inland valleys: primarily west of the Cascade Range in Washington, Oregon and west of the Sierra Nevada in California [27]. In California, Scotch broom occurs on more than 700,000 acres (283,000 ha) in central to northwest coastal and Sierra Nevada foothill regions. Occurrences are also reported further south in the interior valleys of Los Angeles, San Bernardino, Riverside, and Orange counties, and Scotch broom is beginning to invade chaparral and lower montane habitats in the San Bernardino Mountains [123]. Roughly 10% of Vancouver Island is infested with Scotch broom and common gorse (*Ulex europaeus*). Isolated patches of Scotch broom have also been reported along Kootenai Lake and Castlegar in interior British Columbia [104].

Portuguese broom is native to the Iberian Peninsula. It is the least common of the broom species in North America, occurring in California and Oregon. In California, it occurs in the San Francisco Bay area, southern Coast, and Peninsular ranges, where it is locally abundant [55]. It occupies about 65 acres (26 ha) in the Marin Headlands, Marin County, where it was introduced in the 1960s for landscaping and slope stabilization. It now forms a dense cover, with 1 mature shrub per m². It is found occasionally in other parts of the Bay area, and has been reported in Mendocino and San Diego counties [4]. Plants database provides state distribution maps of Scotch broom and its infrataxa and of Portuguese broom.

Scotch broom and Portuguese broom are 2 of 4 nonnative invasive broom species that occur in North America. Spanish broom (*Spartium junceum*) and French broom (*Genista monspessulana*) occur in similar habitats and have some similar morphological and ecological characteristics. Common gorse is another leguminous shrub that occurs in similar habitats, but is morphologically distinct from the brooms.

The following lists include vegetation types in which Scotch broom and Portuguese broom are known or thought to be potentially invasive, based on reported occurrence and biological tolerances to site conditions. These mostly apply to Scotch broom; as described above, Portuguese broom has a very limited North American distribution. Precise distribution information is limited, especially in eastern North America; therefore, these lists may not be exhaustive.

ECOSYSTEMS [46]:
FRES10 White-red-jack pine
FRES12 Longleaf-slash pine
FRES13 Loblolly-shortleaf pine

FRES15 Oak-hickory
FRES17 Elm-ash-cottonwood
FRES18 Maple-beech-birch
FRES19 Aspen-birch
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES24 Hemlock-Sitka spruce
FRES27 Redwood
FRES28 Western hardwoods
FRES34 Chaparral-mountain shrub
FRES37 Mountain meadows
FRES41 Wet grasslands
FRES42 Annual grasslands

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

AL	CA	CT	DE	GA	HI	ID	KY	ME	MD
MA	MI	MT	NH	NJ	NY	NC	OH	OR	PA
SC	TN	UT	VA	WA	WV	DC			

CANADA

BC	NS	PE

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

KUCHLER [66] PLANT ASSOCIATIONS:
K001 Spruce-cedar-hemlock forest
K002 Cedar-hemlock-Douglas-fir forest
K005 Mixed conifer forest
K006 Redwood forest
K009 Pine-cypress forest
K010 Ponderosa shrub forest
K025 Alder-ash forest
K026 Oregon oakwoods
K028 Mosaic of K002 and K026
K029 California mixed evergreen forest
K030 California oakwoods
K033 Chaparral
K034 Montane chaparral
K035 Coastal sagebrush
K036 Mosaic of K030 and K035
K048 California steppe
K073 Northern cordgrass prairie
K098 Northern floodplain forest

SAF COVER TYPES [41]:

217 Aspen
221 Red alder
222 Black cottonwood-willow
223 Sitka spruce
224 Western hemlock
229 Pacific Douglas-fir
230 Douglas-fir-western hemlock
232 Redwood
233 Oregon white oak
234 Douglas-fir-tanoak-Pacific madrone
236 Bur oak
237 Interior ponderosa pine
243 Sierra Nevada mixed conifer
244 Pacific ponderosa pine-Douglas-fir
245 Pacific ponderosa pine
246 California black oak
247 Jeffrey pine
248 Knobcone pine
249 Canyon live oak
250 Blue oak-foothills pine
255 California coast live oak

SRM (RANGELAND) COVER TYPES [121]:
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
201 Blue oak woodland
202 Coast live oak woodland
203 Riparian woodland
204 North coastal shrub
205 Coastal sage shrub
206 Chamise chaparral
207 Scrub oak mixed chaparral
208 Ceanothus mixed chaparral
209 Montane shrubland
214 Coastal prairie
215 Valley grassland
216 Montane meadows
217 Wetlands
313 Tufted hairgrass-sedge
409 Tall forb
411 Aspen woodland

HABITAT TYPES AND PLANT COMMUNITIES:
The following description of habitat types and plant communities in which Scotch broom and Portuguese broom occur is taken from examples found in the literature. The objective is to provide examples of vegetation types in which these species occur, and is not meant to imply that they are restricted to these types within these areas. For Scotch broom most examples come from areas where Scotch broom is most widespread and most invasive. In some areas, particularly the eastern U.S., there is little to no information on vegetation types in which Scotch broom occurs. There is very little information in the literature on vegetation types in which Portuguese broom occurs.

Scotch broom threatens endangered ecosystems such as Oregon white oak (*Quercus garryana*) woodlands in southwestern British Columbia, adjacent Washington, and Oregon by interfering with the establishment and spread of many rare and endemic species found in these endangered ecosystems ([98] and references therein).

In **British Columbia**
Scotch broom dominates many sites in the Cowichan Garry Oak Reserve. The Reserve is a highly fragmented Oregon white oak savanna ecosystem extending along the coastal areas of southeastern Vancouver Island, and supports many nonnative, invasive species. The most abundant native species include common camas (*Camassia quamash*), mosquito bills (*Dodecatheon hendersonii*), long-stolon sedge (*Carex inops*), and Idaho fescue (*Festuca idahoensis*). The most abundant nonnative species include Kentucky bluegrass (*Poa pratensis*), orchard grass (*Dactylis glomerata*), and sweet vernalgrass (*Anthoxanthum odoratum*) [70]. Scotch broom may be associated with coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*), Pacific madrone (*Arbutus menziesii*), common gorse, and Himalayan blackberry (*Rubus discolor*) [98]. It also occurs in the coast forest area dominated by western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), and broadleaf maple (*Acer macrophyllum*) [149].

Scotch broom is invasive in several plant communities in the Puget Trough area of western **Washington**, including Idaho fescue
grasslands and Oregon white oak woodlands. These plant communities are heavily impacted by nonnative species, among which Scotch broom is one of the most common and widespread. Native animal and plant species that are threatened with habitat loss include several federally listed species and species of concern: the western gray squirrel, the western pocket gopher, several species of birds, reptiles, amphibians, and butterflies including the mardon skipper and valley silverspot, and several plant species including Columbian whitetop aster (*Seriorcarpus rigidus*), longhair sedge (*Carex comosa*), greenfruit sedge (*Carex interrupta*), smallflower wakerobin (*Trillium parviflorum*), Torrey's pea (*Lathyrus torreyi*), and golden Indian paintbrush (*Castilleja levisecta*) [23].

In one grassland community at Fort Lewis Military Reservation in the Puget Trough, stands of Scotch broom are replacing a prairie community dominated by Idaho fescue and small herbaceous perennials such as common camas and rigid whitetop aster (*Symphyotrichum retroflexum*) [51]. In many areas most native prairie species have low cover values or are absent. Shade tolerant grasses and forbs such as colonial bentgrass (*Agrostis capillaris*), Kentucky bluegrass, and Pennsylvania sedge (*Carex pensylvanica*) are the dominant graminoids, and wall bedstraw (*Galium parisiense*) is the dominant forb under Scotch broom. Other nonnative species that have higher cover under Scotch broom compared to uninvaded prairie include common St. Johnswort (*Hypericum perforatum*), common velvetgrass (*Holcus lanatus*), and blue fieldmadder (*Sherardia arvensis*). The only species that did not differ in cover between Scotch broom-invaded and uninvaded sites was another nonnative species, oxeye daisy (*Leucanthemum vulgare*). Bare soil occurred in many areas under dense Scotch broom cover. Most native prairie species are present as occasional relics under gaps in the Scotch broom canopy. As gaps close with stand age, the remaining native prairie plants are lost, leaving only colonial bentgrass and nonvascular cryptogams as the dominant understory components [139]. Another study at Fort Lewis found Scotch broom in all site types identified within Oregon white oak communities, but most commonly on sites with an oak overstory and an understory characterized by long-stolon sedge and blue wildrye (*Elymus glaucus*), and by the nonnatives colonial bentgrass and common St. Johnswort. Several other nonnative species were also common on these sites, which had the lowest diversity and evenness values of the 3 site types identified [135]. At Nature Conservancy preserves in Washington, Scotch broom occurs in lowland prairies where it displaces native species and may impact threatened species such as golden Indian paintbrush, and Whulge checkerspot and Mardon skipper butterflies [109].

A prairie site in the Willamette Valley, **Oregon**, contains both native wetland dominated by tufted hairgrass (*Deschampsia caespitosa*) and upland prairie vegetation invaded by Scotch broom [26]. Where prairies in the Willamette Valley have been invaded by woody species including Scotch broom, lupines (*Lupinus* spp.) and other nectar plants for the Fender's blue butterfly are shaded out, thus impacting habitat for this endangered species [115]. At Nature Conservancy preserves in northwest Oregon, Scotch broom occurs in grassland and forest communities where it may interfere with threatened species such as Columbian whitetop aster (*Aster curtus*) and upland larkspur (*Delphinium leucophaeum*) [109]. Scotch broom occurs in Douglas-fir-western hemlock stands in western Oregon [7], but is infrequent along roads and streams on the western slope of the Cascade Range, where native vegetation is dominated by western hemlock at lower elevations and Pacific silver fir (*Abies amabilis*) at higher elevations. Scotch broom occurrence had no detectable trends with site type (type of road), but was more common along roads than streams [82]. At Myrtle Island Research Natural Area in Oregon, Scotch broom is frequent in red alder-Oregon ash (*Alnus rubra-Fraxinus latifolia*)/Himalayan blackberry/reed canarygrass (*Phalaris arundinacea*) and Oregon white oak/Scotch broom/redtop (*Agrostis gigantea*) plant community types [133].

In **California** Scotch broom occurs in the northwest humid coast belt or redwood (*Sequoia sempervirens*) transition life zone, the Sierra foothills gray pine (*Pinus sabiniana*)-chaparral belt, and the lower part of the ponderosa pine (*Pinus ponderosa*) belt of the Sierra Nevada [16,149]. Scotch broom also invades coastal grasslands. Scotch broom and French broom are persistent problems along roadsides in the redwood region of California. Scotch broom establishes in redwood forests after clearcutting and persists until the canopy closes [113]. Scotch broom also occurs on prairie sites, in the Bald Hills area of Redwood National Park, with mixed annual grasses and forbs [16]. Scotch broom invades valley grassland and foothill oak (*Quercus* spp.) woodlands in California, occurring up to middle elevations in the Sierra foothills, and there is concern that it and other invasive species will continue to move upslope in the Sierra. Scotch broom is found in several California counties within the Sierra Nevada, primarily around the ponderosa pine forest-chaparral transition, but also along roadsides across both of these community types [116]. It occurs on an oceanside slope at Point Reyes National Seashore, sharing dominance with coyote bush (*Baccharis pilularis*), on a site previously used for cattle grazing [78]. Scotch broom occurs, interleaved with French broom, on hillslopes dominated by nonnative grasses, with patches of coyote bush and several nonnative forbs and shrubs including bigleaf periwinkle (*Vinca major*), silverleaf cotoneaster (*Cotoneaster pannosus*), narrowleaf plantain (*Plantago lanceolata*), evergreen blackberry (*Rubus laciniatus*), and poison hemlock (*Conium maculatum*) at Mt. Tamalpais State Park. Overall cover of Scotch broom and French broom at this site was about 15% and 30%, respectively. At China Camp State Park, Scotch broom and French broom grew in patches and as scattered individuals, with a total cover of about 15% and 35%, respectively, and associated with coyote bush, toyon (*Heteromeles arbutifolia*), poison-oak (*Toxicodendron diversilobum*), nonnative musk thistle (*Carduus nutans*), and several nonnative grasses including Uruguayan pampas grass (*Cortaderia selloana*) [88].

There is very little habitat information available for Scotch broom in eastern North America, probably because "it is a poor competitor with the local lush vegetation of the eastern states" [149] (see Site Characteristics). Shanks and Goodwin [118] report that it is well established in a sandy field in Mendon Ponds Park, New York.

In Prince Edward Island and Nova Scotia, Scotch broom may be associated with annual grasses, forbs, and other weedy plants such as goldenrod (*Solidago canadensis*) and thistles (*Cirsium* spp.) as well as trees and shrubs found in open woodlands [98].

There is no habitat information available for Portuguese broom in North America. In its native range, Portuguese broom occurs in mixed maquis shrubland with strawberry tree (*Arbutus unedo*), briar root (*Erica arborea*), gum rockrose (*Cistus ladaniferus*), *Erica australis*, *Phillyrea angustifolia*, and *Halimium ocymoides* in the western half of the Iberian Peninsula [54].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Cytisus scoparius, C. striatus

- GENERAL

Scotch broom

Portuguese broom

GENERAL BOTANICAL CHARACTERISTICS:
Scotch broom and Portuguese broom are 2 of 4 nonnative invasive broom species that occur in North America. All are perennial, leguminous shrubs. DiTomaso [35] provides a table of characteristics to distinguish among broom species and common gorse. All species occur in similar habitats and Scotch, Portuguese, and French broom have similar morphological characteristics. Common gorse also occurs in similar habitats but is morphologically distinct from the brooms. Portuguese broom is often misidentified as Scotch broom; however, Portuguese broom is neither as widely distributed nor as common as Scotch broom (see Distribution and Occurrence). Less is known about the biology and ecology of Portuguese broom, but it is thought to have ecological characteristics similar to Scotch broom [35].

The following descriptions of Scotch and Portuguese broom provide summaries of the range of characteristics described in several reviews [4,17,35,60,98] and florae [48,55,57,101,105,126,154]. They provide characteristics that may be relevant to fire ecology, and are not meant for identification. Keys for identification are available for Scotch broom (e.g. [48,55,57,105]) and Portuguese broom (e.g. [55]).

Scotch broom is a long-lived, erect, bushy shrub with stiff, slender branches. It grows 6 to 12 feet (2-4 m) tall. Stems are hairy when young and glabrous as they mature. On young branches leaves are usually 1-foliate and sessile, becoming 3-foliolate and petiolate to subsessile on older branches. Leaflets are 0.3 to 0.7 inch (5-20 mm) long and 1.5 to 8 mm wide. Scotch broom's inflorescences are axillary clusters or terminal racemes. Axillary clusters have 1 to 2 pea-like flowers per cluster. Flowers are15 to 25 mm long, and occur singly or in pairs in leaf axils on short pedicels less than 0.5 inch (12 mm) long; or in elongated, terminal, leafy racemes. The fruit is a flat dehiscent legume, 1 to 3 inches (2.5-7 cm) long and 8 to 13 mm wide long, with hairs along the seam. Seeds occur 3 to 12 per pod, and bear elaiosomes. No information is available on the size of Scotch broom's root system, other than it is "deep" with a forked taproot.

Portuguese broom is a shrub, 6 to 10 feet (2-3 m) tall. Young plants, 1 to 3 years old, have an upright form dominated by a leading apical stem. Plants become more branched and broaden with age. In windy locations growth is more compact and stunted, with plants growing 3 to 5 feet (1-1.5 m) tall. Branches are slender, and covered sparsely by small leaves consisting of 1 to 3 leaflets. Leaflets are 0.3 to 0.5 inch (5-15 mm) long, sessile on upper branches and short-petioled on lower branches. Leaves are more abundant at outer ends of actively growing branches. Portuguese broom's inflorescence is a cluster, with 1 to 2 pea-like flowers per cluster, occurring in leaf axils on pedicels 5 to 10 mm long. The fruit is a legume, 0.7 to 1.8 inches (15-40 mm) long and densely white-hairy. Number of seeds per pod is variable, and usually several (~5-9) per pod.

The leaves of Scotch broom and Portuguese broom are deciduous early in the season, or at times of stress, and both have green, photosynthetic stem tissue, with the ratio of woody to green material increasing as plants age [35]. Research on stem photosynthesis has been conducted on Scotch broom and Spanish broom [12,78]. These species rely heavily on stem photosynthesis during the hot summer months, and are well adapted to open, high sunlight environments. However, drought stress severely inhibits photosynthesis of brooms [78]. In Scotch broom, about half the photosynthetic tissue is in the leaves and half in the stems. Both leaf and stem photosynthesis make important contributions to growth and biomass production in Scotch broom. Stem photosynthesis gives Scotch broom many advantages, including the ability to photosynthesize after defoliation by herbivores or drought-induced leaf fall [12].

Scotch broom and Portuguese broom have nitrogen-fixing bacteria located in nodules on their roots. This facilitates growth and establishment in low nitrogen soils. Nitrogen fixation is affected by both temperature and moisture and occurs in Scotch broom at temperatures down to 38 ºF (4 ºC) ([17] and references therein), and moisture stresses down to -0.5 Mpa [97]. Studies in Monterey pine (*Pinus radiata*) plantations in New Zealand found Scotch broom was an effective nitrogen fixer, deriving 81% of nitrogen in its aboveground tissues from the atmosphere, which is equivalent to 111 kg N/ha/year. Isotopic nitrogen analysis suggests that there was some transfer of fixed nitrogen from Scotch broom to the Monterey pine trees [151].

There are no reported studies on the nature and extent of Scotch broom or Portuguese broom mycorrhizal associations [98].

Growth form and stand structure:

Scotch broom has a wide range of growth habit, including prostrate and upright forms. Growth habit may be genetically determined, and has been used in Europe to distinguish infrataxa (e.g. [47]). Variability in prostrate and upright forms in young plants may also be related to light and/or moisture availability [97]. Additionally, researchers from Australia indicate that stems of Scotch broom may become weak with age, such that plants are partly prostrate [60,122].

Brooms sometimes form dense, brushy stands that are "practically impenetrable" [56]. Population densities are higher in nonnative versus native habitats [91]. Parker [85] describes 3 years of population demographics and changes in stand structure, biomass, and density in Scotch broom populations in Washington prairie remnants and in urban fields. Scotch broom invasion involves a dramatic increase in density from scattered plants to a near monoculture. Total Scotch broom biomass increased monotonically with invasion stage, and later stages produced several kilograms of plant material per square meter [85]. Stands can attain a biomass of over 44,000 to 50,000 kg/ha in 3 to 4 years [13]. Population densities varied significantly ($P<0.05$) between Europe, Australia, and New Zealand, and were significantly lower in Europe [91].

As Scotch broom stands age, the ratio of woody to green material also increases, and dead wood accumulates [150]. A review by Hoshovsky [59] describes older broom stands as "a mosaic of dead, partly dead and living plants." The ratio of dead to live fuel is critical in determining combustion in California shrublands [65], and several authors suggest that dense broom stands create a serious fire hazard [23,35,89,139] (see Fire Management Considerations).

RAUNKIAER [106] LIFE FORM:
Phanerophyte

REGENERATION PROCESSES:
Scotch broom and Portuguese broom reproduce and spread from abundant seeds and both can sprout from stumps or root crowns following damage or destruction of aboveground biomass [4,17,35].

Breeding system: Scotch broom flowers are perfect. Vivipary has not been reported [98]. Scotch broom is monoecious and does not show appreciable levels of selfing [88,129]. Portuguese broom is monoecious [55].

Pollination: The large yellow flowers of Scotch and Portuguese broom are pollinated by several species of bee [35,98], and possibly other insects [122]. Only a small proportion of flowers develop into fruit (<50%) [35,122]. Parker and others [84,88] demonstrated pollinator limitation in both Scotch broom and French broom, underscoring the potential importance of pollinators to the fecundity and spread of these species. Because nonnative honeybees are often the most common pollinators of broom [87,129], potential negative impacts of beekeeping on broom management have been suggested [87].

Scotch broom produces flowers that are "tripped" open when pollinated and has a nearly obligatory relationship with bumblebees and honeybees in Washington. Less than 1% of untripped flowers produce fruits, and outcross-pollinated flowers produce 4 times as much fruit as self-pollinated flowers [84].

Suzuki [128,129] studied pollination biology in Scotch broom in Japan and found 40.26% of flowers were visited by effective pollinators, 28.91% were pollinated, and 13.75% matured fruits (N=2,600). Therefore, 71.8% of visited flowers were pollinated and 47.58% of pollinated flowers matured fruits. Pollinator visitation rate was higher for plants in sunny habitats than for those in shade. Nineteen species of insects visited flowers. The author concluded that pollinator limitation is the most limiting factor for Scotch broom fruit production and that resource limitation was secondary, yet more severe in larger plants [128]. Similarly, on study sites in Washington, mean pollinator visitation rate was low, ranging from 3% to 30% among 4 Scotch broom populations over 3 years. Urban populations received higher numbers of visits than did 2 native prairie sites. Hand-pollination experiments revealed significant ($P<0.0001$) pollinator limitation in all populations over 2 years. Prairie populations were more pollinator limited than urban populations. Significant correlations were found between pollinator visitation and whole-plant fruit production in all 3 years. Simulations over a short time scale (10-30 years) demonstrated little effect of pollen limitation on urban populations, but a potentially large effect of increasing pollinator visitation in the rapidly invading prairie populations [84].

Seed production:

Broom seed production varies from year to year, and can vary among species and site conditions. Scotch broom becomes reproductive on reaching an age of 2 to 3 years and a height of about 2 to 3 feet (0.6-1 m) [17,60,98], unless damaged or otherwise suppressed [122]. Portuguese broom becomes reproductive at 2 to 3 years of age at a height of 1.5 to 3.3 feet (40-100 cm) [4]. In an Australian study, comparing recruitment of Scotch broom among sites with different disturbance histories, time between recruitment and flowering varied between 2 and 5 years, depending on habitat. Seed production per plant was unaffected by site, stand maturity, grazing, disturbance, or cohort, but was related to plant density [120]. On some sites a second, less prolific flowering occurs in summer [89,97].

Several estimates of seed production in Scotch broom plants under various site conditions in both its native range and in invaded communities are available in the literature. Mature Scotch broom shrubs produce anywhere from a few hundred to over 7,000 pods per plant, with a range of zero to 22 seeds per pod (about 5 to 8 on average) [60,98,122,150]. One medium-sized Scotch broom shrub can therefore produce several thousand seeds per year [13,16,60]. Factors that may affect seed production in Scotch broom include predation by insects, site conditions, plant size, climatic conditions (i.e. drought), plant age, and individual plant physiology.

Predisperal predation by insects may reduce Scotch broom seed yield by as much as 75% in its native habitat. In its native range, Scotch broom plants at least 3 years old produced 1,242 to 7,104 pods per bush in sprayed (to eliminate insect herbivores) shrubs, and 319 to 2,718 in unsprayed shrubs. The number of seeds per pod ranged from 6.9 to 9.84 in sprayed and from 4.54 to 8.04 in unsprayed shrubs [150]. Unripe seeds and pods are largely free from predation in North America, New Zealand, and Australia [35,122]. Dense stands of Scotch broom can produce 4,000 to 20,000 seeds/m²/year ([35] and references therein). Seed production under broom canopies beneath and outside a eucalyptus overstory on a site in New South Wales was 107 and 8,885 seeds/m², respectively (A. Sheppard and P. Hodge, unpublished data cited by [60]).

Results presented by Williams [97] indicate variation in seed production among sites in New Zealand, with a trend toward lower seed production in higher elevation sites (above 2,800 feet (854 m)) and on poorly developed floodplain soils:

Site	Soil	Elevation	Shrub age (yrs)	% fruiting	pods/bush	seeds/p	
						1st flowering	2 fl
gardens	recent, silt loam	27 m	2	100	2,200 ± 1,500[a]	9.3 + 2.0	3
river bed	coarse alluvium	137 m	2	0	0	--	--

river bed	coarse alluvium	274 m	2	20	1 ± 1	--	--
river bed	coarse alluvium	274 m	5	100	--	8.64 + 3.2	--
high country	brown earth, silt loam	854 m	2	100	84 ± 60	8.12 + 2.0	3
high country	brown earth, silt loam	1082 m	2	18	2 ± 2	6.6 + 3.9	4
high country	brown earth, silt loam	1311 m	2	20	1 ± 1	7.7 + 4.7	--

[a] standard deviation

A study of Scotch broom in California found drought and plant size affected seed production. The following data are from the first 2 years of a 3-year study at 2 California sites where 5 Scotch broom shrubs over 3 feet (1 m) tall were included in each sample. "Damage" is from seed weevils. No information is given on time periods when early and late flowering occurred [16].

	Early flowering shrubs		Late flowering shrubs	
Year	1987	1988	1987	1988
Mean # of pods/shrub	2,891	1,287	3,876	1,400
Mean # of seeds/pod	8.1	2.9	8.1	2.4
% of seed damaged	5	5	80	91
Mean # pods/shrub/year (early + late flowering shrubs for 1987-1988)				2,363
Mean # seeds/pod (early + late flowering shrubs for 1987-1988)				5.37
Total mean # seeds/shrub/year				12,701

The number of pods and seeds decreased significantly ($p<0.01$) for both early and late flowering shrubs during 1988 (a drought year) compared with 1987 and 1989. The number of pods per shrub had a linear positive dependence on shrub volume for both early and late flowering shrubs during the 3 years of study [13]. Similarly, Parker [85] found that fruit production increased dramatically with plant size in Scotch broom, while invasion stage did not have an impact on fecundity.

Waloff and Richards [150] cite evidence that Scotch broom produces fewer pods per plant (by weight) as plants age. However, Smith and Harlen [122] observed that the proportion of flowers that develop into fruits, as well as the number of flowers overall, tends to increase with shrub age and size. They also found that seed production per unit area did not change with stand age between 6 and 24 years [122].

A biennial cycle of relatively low and high pod density was observed in Scotch broom in its native range. Since the timing of these cycles did not coincide between treatment plots on the same site, seed production was thought to be independent of climatic conditions and reflected more the physiology of individual plants [150].

Seed dispersal:

Short distance transport of broom seeds is similar to that of many other legume species and involves "ballistic" dispersal. As pods mature and dry, the 2 pod halves split and wrap in alternate directions, audibly snapping apart and catapulting the seeds [17,98,101,122]. Ballistic dispersal of seeds resulted in a mean dispersal distance of 3 feet (96 cm), a median distance of 44 inches (112.8 cm), and a maximum distance of 213 inches (540 cm) at 2 California sites [16]. In Australia, Smith and Harlen [122] found that most Scotch broom seed falls within 3.3 feet (1 m) of parent plants, and rarely beyond 10 to 13 feet (3-4 m) without assistance from wind or insects. Robertson and others [111] found that Scotch broom seed was dispersed as far as 33 feet (10 m) from the edge of thickets, although the means of dispersal was not studied.

Scotch broom seeds bear elaiosomes that attract ants [95]. After seeds disperse from the pods, ants gather them and typically carry them back to their nest, where they eat the elaiosome. Removal of the elaiosome does not kill the seed nor affect seed germination, and Scotch broom plants may be found in high density around ant nests on some sites. Foraging behavior of ants varies, and not all ants carry seed to their nests [14,16]. Bossard [16] measured mean dispersal distance by ants at 3 feet (96 cm) and maximum dispersal distance at 207 inches (525 cm) at California study sites. Ant dispersal in Australia has only been measured for short distances, up to 3.3 feet (1 m) [122]. Birds and animals may also play a part in broom seed dispersal, although seed predation by birds and other animals is considered negligible [35]. When Scotch broom seeds were fed to domestic goats, 8% of the seeds remained viable following ingestion [58]. Smith and Harlen [122] also suggest evidence that Scotch broom seed may be dispersed in the feces of a variety of animals such as horses.

Spread of Scotch broom along riverbanks strongly suggests seed dispersal by water [35,97,122]. Williams [97] indicated that the hard seed coat of Scotch broom can survive long distance transport in rivers and streams, and viable seed was recovered from stream sediments up to 160 feet (50 m) downstream from Scotch broom shrubs [122].

Scotch broom distribution patterns along roads and in work sites suggest transport by vehicles and equipment. Additionally, samples taken from recreationist's vehicles (inside and out) and shoes held many Scotch broom seeds [122]. Construction crews can disperse broom seeds long distances by transporting contaminated soil or gravel [35,98].

Portuguese broom probably spreads like Scotch broom, with the same seed dispersal mechanisms. Portuguese broom seeds are released ballistically from the pod, then further dispersed by animals and water runoff [4].

Seed banking:

Portuguese broom and Scotch broom have hard seed coats that delay germination for months or years and enable seeds to survive in the soil seed bank for at least 5 years and possibly as long as 30 years ([17] and references therein). Other estimates of Scotch broom seed longevity indicate that some seed may survive as long as 80 years under conditions of dry storage ([35,60] and references therein).

Studies carried out on Scotch broom seeds from a foothill site on the El Dorado National Forest in California showed that fresh seed was 98% viable but that >65% of seeds were dormant. About 7% of seed remained ungerminated after 3 years at 1.5 inches (4 cm) below the soil surface [14]. In Australia, 69% to 83% of seeds displayed dormancy in an experiment using seeds collected in the field and stored in the lab for 6 months. Seed buried for 182 to 1,371 days were 90% dormant upon recovery. Viability was also retained for similar periods by seeds stored under water [122]. Williams [97] found an average of 68 Scotch broom seeds per m^2 in the top 4 inches (10 cm) of soil and 51 seeds per m^2
in the 4 to 8 inches (10-20 cm) depth along rivers in New Zealand. Of these, a highly variable number (0-100%) was dormant at the time of sampling [97].

Scotch broom seed dormancy and longevity contribute to large soil seed banks. Seed bank density under mature broom stands is highly variable [120]. In its native range, soil seed banks below a mature broom canopy vary from 430 to almost 20,000 seeds per m^2 [2,40,60,93]. Scotch broom seed density on a grassland site in England was not affected by exclusion of insects, mollusks, or rabbits [40]. Soil seed banks below mature broom canopies in Australia varied from 190 to 2,700 per m^2 in the Adelaide Hills, 1,100 to 12,300 per m^2 at Barrington Tops, and 4,630 to 27,400 per m^2 around Braidwood. Less than 2% of the seeds extracted from the soil were nonviable ([60,122] and references therein). Broom seeds were usually most abundant in the top 1 inch (2.5 cm) of soil [122]. Average densities ranged from 0 to 2,649 seeds per m^2 under Scotch broom in New Zealand, and seed viability was 90% to 100% [3].

No consistent relationship is found between seed bank density and stand age. Patterns observed at Barrington Tops, Australia, suggest an increase in seed bank density with stand age for several years [122]. However, in the absence of seed rain the seed bank declined by about 50% over 1 year at another site (Sheppard and Hodge, unpublished data in [60]). Seed bank densities under Scotch broom plants of varying age class in New Zealand tended to be highest under plants between 6 and 10 years old, but varied among sites [3].

Managers should be alert to the possibility of Scotch broom seed in the soil seed bank, even in areas where broom is no longer present in aboveground vegetation. Loss of seeds from the soil seed bank is mainly through germination and not mortality. At a California foothills site, seed bank germination was substantial 3 years after the removal of mature broom plants. The mean number of seedlings establishing from the seed bank ranged from 120 to 161 seedlings per 0.25 m^2 at the end of the 2nd germination period, and 15 to 25 seedlings per 0.25 m^2 at the end of the 3rd germination period. There was no evidence of insect or vertebrate herbivory affecting the density, biomass, relative growth rate, or seedling germination of Scotch broom at this site [16]. Persistent, deeply buried seed banks of Scotch broom were found at 2 study sites in New Zealand, 1 of which lacked Scotch broom in aboveground vegetation. Scotch broom may establish from the seed bank following disturbance, especially fire [90], as improved seed permeability may be brought about by scarifying the seed coat during disturbance [98,122].

Germination:

Scotch broom seeds imbibe water and swell to 3 times their original size before germination. However, not all imbibed seeds germinate; some return to their original size and remain dormant [60]. Bossard [14] found that seed germination occurs best after a period of dormancy at temperatures between 39 to 91 °F (4-33 °C), with 64 to 72 °F (18-22 °C) being optimal. Germination rates are highest in the top inch (2 cm) of soil, and Scotch broom seedlings do not emerge from below 3 inches (8 cm) [14]. In experimental treefall gaps in New Zealand, Scotch broom seeds germinated most successfully on sites exposed to direct solar radiation, with or without litter; percent germination increased as exposure increased, while litter had no significant ($p<0.001$) effect on germination [72].

Most seed (often 100%) produced by Scotch broom is viable, but a large percentage of fresh seed is dormant (see Seed banking) and requires scarification before germination can occur. Scarified seeds can germinate throughout the year under suitable conditions [14]. Conditions terminating dormancy in Scotch broom seeds are not entirely clear. Mechanical and chemical scarification may induce germination (e.g. [122]). Heat scarification also induces germination, as indicated in laboratory studies [14,122,131] and field observations of postfire broom seedling establishment (see Fire Effects). On some sites, soil disturbance may also scarify seed and/or terminate dormancy and induce germination [11], although this relationship is not consistently observed among sites [86].

An Australian study found that scarification using fine sand paper induced 100% germination in Scotch broom seed, but with 8% to 12% mortality. Treatment of seeds with sulfuric acid also increased germination rates. Heat treatment (pouring boiling water over seeds in a flask then allowing it to cool to room temperature) led to 48% to 60% germination, although the same procedure using water at 176 °F (80 °C) had little effect [122].

Germination and seedling recruitment are sometimes favored by soil disturbance [17], but disturbance effects may vary among plant communities [86]. In California, Scotch broom germination at one site increased when soil was disturbed. At another site in this study, quail and blue grouse preferentially foraged in disturbed areas, and the interaction of these seed predators and seed dispersers (ants) modified the abiotic effects of habitat disturbance on seedling establishment, resulting in no significant differences in seedling recruitment between disturbed and undisturbed sites [11]. At Weir Prairie in Washington, however, undisturbed plots had significantly ($P<0.004$) higher germination rates and seedling establishment than scraped (cryptogams removed) or burned plots. Field observations and unpublished data cited by the author support the notion that soil disturbance does not favor Scotch broom seed germination in Washington prairies [86]. Similarly, Shepphard and others [120] found that soil cultivation following broom removal did not enhance germination rates of Scotch broom at 3 sites in Australia. Differences in Scotch broom seed germination in response to disturbance may be influenced by plant community composition and structure. Sites dominated by turf-forming grasses or mature stands of Scotch broom might be expected to show a positive effect of soil disturbance on Scotch broom establishment [36]. For example, in experiments in mature Scotch broom stands in France and England, cultivated plots showed much higher germination rates than control plots [86]. Effects of disturbance on seedling establishment are difficult to generalize from one population or habitat to another [11].

Portuguese broom seed germination requirements are probably similar to related broom species such as Scotch broom [4]; however, research is needed to test this assumption.

Seedling establishment/growth:

Scotch broom seedling establishment and growth may be affected by several variables including depth of seed burial, soil type, soil moisture, stand density, and site disturbance.

Depth of seed burial and substrate texture affect Scotch broom seedling emergence. In greenhouse experiments, Williams [97] found that seedlings failed to emerge from seeds buried 4 inches (10 cm) deep. Seedlings emerged more rapidly and successfully from 1.2 inches (3 cm) than from 2 inches (5 cm); and more rapidly from fine substrate than coarse substrate at both these depths [97]. Soil moisture content was significantly correlated (r^2=0.048 and 0.078; $P< 0.05$) with seedling establishment at 2 sites in California [11].

Seedling mortality differed with location within established Scotch broom stands. Survivorship was lower in the center of the population, where intraspecific density was very high, than at the edge. Germination rates were also lower in the center of the population and declined consistently from the edge to the center [85]. There was no evidence of density dependent seedling mortality in a study at Weir Prairie, and seedling establishment was influenced more by germination rates [86].

Scotch broom is said to readily colonize nitrogen-poor, seasonally moisture-stressed, disturbed areas like sand dunes, riverbeds, roadsides, and steep slopes [16,97]. In an Australian study, comparing recruitment of Scotch broom among sites with different disturbance histories and subjected to different disturbances (cutting mature plants with and without soil cultivation) between populations in Europe and Australia, seedling mortality rates were higher in Australia and were not affected by timing of establishment. More broom seedlings survived year-to-year in grazed vs. ungrazed plots; in cultivated (to 10 cm, resembling disturbance by pigs and wombats) vs. cut (mature broom removed) vs. undisturbed plots; and in immature vs. mature stands. The presence of other vegetation had little effect on Scotch broom seedling recruitment, age at flowering or the percentage cover of broom [120].

Rapid development of both roots and foliage enable Scotch broom to invade and persist in new habitats. The deep rooting habit, small leaf size, and rapid growth (height and girth) are morphological characteristics that help to enhance its survival. After 2 years, Scotch broom may be 8 feet (2.5 m) in height, with a stem diameter of 1 inch (2 cm). When grown under full light in greenhouse conditions, 65-day-old Scotch broom plants attained slow vertical growth, allocating 48% of weight gain to the roots. When light intensity was reduced to 30% full sunlight, the young plants were 3 times as tall and had a poorly developed and weakly nodulated rooting system [97].

Broom plants grow rapidly in the first 4 to 5 years, and growth slows considerably thereafter. Growth appears to be more vigorous in introduced habitats that lack native invertebrate predators [150]. However, in a comparison of Scotch broom populations in Europe, Australia, and New Zealand, growth rates did not differ among native and nonnative populations, and the tallest plant recorded was in its native range in Spain [91]. Interference can reduce the growth rate of broom seedlings in both native [93] and nonnative [120] habitats [91].

In New Zealand, growth of Scotch broom at low altitudes on moderately fertile soils is more rapid than on sites with nutrient-poor soils or at high altitudes [97].

Asexual regeneration:

Broom plants can sprout from the root crown after cutting or freezing and sometimes after fire; particularly in the rainy season [4,17]. Sprouting varies with timing and degree of top growth removal [4,13] (also see Physical/mechanical control).

SITE CHARACTERISTICS:

General landform/land use type:

Scotch broom is well adapted to dry hillsides (often on steep slopes), pastures, and forest clearings [30,89,117]. In eastern North America, Scotch broom typically occurs near areas where it was purposely planted [9,48,105,126,147], in open woods [105,112], old fields and pastures [19,112], along roadsides, and in other disturbed areas [105,112,160]. Its occurrence is also noted on sandy substrates such as dunes and beaches [48,117].

In western North America, Scotch broom occurs on similar sites [30,59,101,103]. It is invasive on coastal sites from Monterey, California, to Washington state [78], especially in areas where it was planted for dune stabilization [62]. In California, Scotch broom has spread extensively in grassland areas on open hills and invades chaparral and lower montane habitats in the San Bernardino Mountains [123]. It also invades upland areas in the Central coast [39]. Scotch broom is also common in riparian areas, including riparian sites in the Sierra Nevada [39], and cobble bars on the Olympic Peninsula, Washington [34]. It is also invasive in undisturbed prairie remnants in western Washington (see Succession: Disturbance) [85].

Scotch broom does not grow well in forested areas but invades rapidly following logging, land clearing, and burning [75]. Scotch broom has become a serious pest in logged areas replanted with conifer seedlings [30], and is commonly found on clearcuts and on open sites disturbed and opened by logging, roads, or fire. It also invades natural meadows and open forest [34,98,101].

In New Zealand and Australia, Scotch broom invades similar land types, including pastures and cultivated fields, dry scrubland and "wasteland," native grasslands, previously forested hill country, rocky sites, roadsides, dry riverbeds, other waterways [97,158], and both disturbed and undisturbed woodland and open forest [60]. Regression analysis of aerial map data from a national park in Australia indicates that sparse vegetation and flat terrain are among the variables contributing most to expansion of Scotch broom populations [80].

The limited available literature on Portuguese broom seems to indicate similar site tolerances as Scotch broom; however, Portuguese broom's distribution is more limited [4].

General climate:

Scotch broom inhabits maritime to submaritime cool mesothermal climates with dry summers in moderate to high rainfall areas of humid temperate regions. As elevation and continentality increases the frequency of Scotch broom decreases ([98] and references therein). Distribution of Scotch broom indicates that it is well-adapted to the coastal climate and the drier climate of the Sierra foothills. Scotch broom thrives in coastal areas due, in part, to mild winter temperatures that allow it to photosynthesize and fix nitrogen into the winter [156]. Optimum temperatures for stem photosynthesis range from 68 to 77 °F (20-25 °C), while lower temperatures cause a decrease in stem photosynthesis [77]. Scotch broom has some drought resistance, but does not survive in arid regions [35,59].

Scotch broom is native to the Mediterranean, where its southern distributions are limited by drought and its northern by winter cold ([97], and references therein). Several reviews [30,97,98] indicate that the brooms do not tolerate extreme high or low temperatures. Scotch broom does not do well in areas with very cold winters. Seedlings and young plants are especially sensitive to frost, while mature plants can tolerate fairly severe frosts. Frost appears to have little direct effect on its total height growth as the damaged tips are replaced by growth from lateral buds, but plants may experience considerable dieback after very severe winters [97,98]. Some large Portuguese broom individuals can be killed by an unusually long freeze, perhaps limiting its geographic distribution (Alvarez, personal observation in [4]).

The distribution of Scotch broom in North America is limited in the north and inland by cold winter temperatures. In eastern North America, severe winter conditions and more intense competition from local flora may limit the growth and distribution of Scotch broom more than in western North America. On the Atlantic coast of Canada, Scotch broom occurs on disturbed sites in coastal areas south of 46 °N latitude [98]. In Nova Scotia, Scotch broom does not seem to persist in colder regions inland or northward [112]. On the Pacific coast, Scotch broom occurs in disturbed areas in the southwest coastal British Columbia mainland and adjacent islands. Except for the latter, Scotch broom generally does not occur north of 51 °N in western Canada [98]. The altitudinal limit of broom in New Zealand also appears to be limited by winter cold or winter drought [97].

With sparse leaves and photosynthetic stems bearing sunken stomata beneath thick epidermal wax, Scotch broom is adapted to the high-sunlight, seasonally droughty, Mediterranean environment. Scotch broom is considered to be drought tolerant and can have a water potential of -0.259 Mpa or lower without showing any apparent signs of stress (Bannister 1986, cited in [89]). Scotch broom can tolerate some level of drought stress and invade harsh riverbed environments with mid-summer drought in New Zealand and have the ability to set seed over a wide altitudinal range and under conditions of moisture stress [97]. Nonetheless, Scotch broom seedlings may die in sunny locations during rainless periods, even in cool and humid environments. In Australia, Scotch broom occurs mainly in cool temperate areas. In drier climates, it is restricted to the edge of watercourses and along drainage lines. Scotch broom also invades and persists in treeless vegetation such as subalpine grassland and cleared pasture land. In open areas, tussock grasses protect Scotch broom seedlings from drought and grazing [60].

In North America, brooms occur on sites with moderately dry to very dry moisture regimes (Klinka and others 1989, cited in [98]), but do not survive in extremely arid regions in the southwestern United States [35]. Scotch broom is occasional east of the Cascade Range, where precipitation is above 20 inches (500 mm) per year. In California, water-use efficiency of Scotch broom remained unchanged between spring and summer seasons [77], and daily carbon gain remained constant throughout the year [78]. Although Scotch broom is difficult to grow in the hot valleys of California [75], its occurrence in dry habitats and value for stabilizing sand dunes [62] implies a certain degree of drought resistance [59].

Soils: Literature reviews [17,35,59,60,97,98] indicate that brooms can survive under a wide range of soil conditions and have few constraints to growth on almost any medium. They seem to prefer coarse textured, seasonally dry, well-drained soils and a pH range of 4.5 to 7.5. They do well on sites with low to moderate fertility, but grow only rarely on highly calcareous soils. In the San Francisco Bay area Portuguese broom is particularly common on noncalcareous soils [4].

There is very little empirical information on site tolerances of Scotch broom, and some of the observational or anecdotal information is contradictory. In general, Scotch broom seems to be invasive in dry sandy soils in full sunlight [17,62,149,158], and strongly drained, water-shedding sites (Klinka and others 1989, cited in [98]). However, it may grow best on moist, fertile soils [60]. In Australia, broom occurs on soils derived from a wide variety of substrates, particularly basalt, and is rarely found on undisturbed skeletal sandy soils [60].

Scotch broom also seems to tolerate acid soils, but it is unclear whether is tolerates lime soils. In Europe it is found on moderately leached heathland soils, acidic grasslands, and in sand dunes (Bicher and Larsen 1958, cited in [59]). At 1-year-old mine spoil sites in Kentucky, Scotch broom was among several woody species tested for revegetation. Scotch broom was an average of 3.4 feet (1 m) tall after 4 growing seasons at Site 1 but did not survive at Site 2. Differences in site conditions were as follows [100].

	Parent material	pH	soluble salts	available phosphorus
Site 1	gray and black shales	≤4.5	≤0.5 mmhos/cm	≤7 ppm in about 60% of the samples
Site 2	mixture of sandstone and shale	50% of blocks ≤4.5 50% of blocks ≥7.0	≤0.25 mmhos/cm	≤ 3ppm at 95% of sample sites

Scotch broom can survive on nitrogen-deficient soils and those with very low levels of inorganic phosphorus, but also responds rapidly to increases in phosphorus [16,17,90,97]. Scotch broom prefers nitrogen-medium soils at sites in British Columbia (Klinka and others 1989, cited in [98]).

Elevation: Elevation ranges reported for Scotch broom are as follows:

Place	Elevation Range
California	below 4,000 feet (1,300 m) [17,116]
California (northern and central)	up to 3,300 feet (1,000 m) [55,123]
California (El Dorado County)	500 to 6,500 feet (150-2,000 m) [75]
Australia	0 to 4,800 feet (0-1,450 m) [122]

Portuguese broom is found on sites less than 980 feet (300 m) in California [55].

Altitudinal limit of Scotch broom in New Zealand appears to be determined by winter cold or winter drought. Scotch broom grows more rapidly at low altitudes in New Zealand. Growth (cumulative shoot elongation) was highest on sites at 2,800 feet (854 m) and decreased with increasing elevation. Scotch broom plants flowered as high as 4,600 feet (1,400 m) [97].

SUCCESSIONAL STATUS:
Brooms are early seral colonizers. The dispersal of photosynthetic tissue throughout the crown of Scotch broom, in long stems and small leaves, makes it well adapted to the open environments of early succession [158]. Some authors suggest that broom is shaded out once native species are established (e.g. [113]). Bossard [17] expresses concern, however, that their vigorous growth, along with acidification of the soil (see Impacts), may inhibit establishment of other species.

Disturbance:

Broom stands commonly establish and spread after soil and/or vegetation disturbance (e.g. from roads, logging, herbicide treatments, or fire) in both their native range in Europe [53,93,149] and in introduced areas, such as New Zealand [158], Australia [60,89,122], and North America [11,35,61,69,98,113,116]. Scotch broom populations may be perpetuated by continued disturbance [122]. Scotch broom can also colonize undisturbed grassland, shrubland, and open canopy forest [17,59,60,85,89,101,116]. A review by Hosking and others [60], for example, suggests that Scotch broom can invade undisturbed vegetation in Australia, with seedlings establishing in open microsites such as along wallaby tracks.

Conflicting results from research conducted in North America on the role of disturbance in Scotch broom seedling establishment [11,85] suggests that the response of Scotch broom populations to disturbance is site-specific. Bossard [11] found that soil disturbance favored Scotch broom seedling establishment at 1 California site, and results were inconclusive at a 2nd site. Parker [85] compared populations of Scotch broom growing in urban fields to those growing in prairie remnants in western Washington. Populations in prairies expanded more rapidly, although urban populations were more fecund, due to greater numbers of pollinators (see Pollination). The author noted that while much of Scotch broom habitat is disturbed areas (e.g. urban fields, highway rights-of-way, abandoned lots, landfills, etc.), the most rapid rate of spread in this study occurred in the most pristine habitats. Results of this research suggest that these undisturbed prairie sites are more hospitable for invasion of Scotch broom due to the beneficial influence of native cryptogams [85].

Once stands of Scotch broom are established, small Scotch broom individuals in the understory seem to require the removal of a large dominant plant in order to grow into a large size class [85].

Shade tolerance: Scotch broom's common role as an early seral colonizer [60,158] and its tendency to establish in forest environments following vegetation disturbance that opens the canopy [75,89] imply shade intolerance.

Several reviews indicate that Scotch broom survival is best in high-light areas. Scotch broom is generally intolerant of shade and will not grow in heavily shaded places [35,60,98]. Others suggest that it will usually be shaded out once native species are established [17,158] or forest canopy closes [113]. However, Scotch broom can continue to grow and compete for moisture, space, and nutrients under a partial tree canopy on some sites [98]. It can also invade eucalypt-dominated vegetation where the tree foliage protective cover is less than about 50% (Waterhouse 1988, cited in [60]).

Williams [97] suggests that under low light conditions (10%-30% full sunlight) Scotch broom plants tend to form a single upright shoot and produce sparse foliage and few flowers. In a laboratory study by Vallardes and others [146], seedlings of Scotch broom had greatest survival (~82%) in moderate shade (30% full sunlight), ~30% survival in 100% full sunlight, and ~12% survival in deep shade (3% full sunlight). Rates of net photosynthesis were significantly ($P<0.005$) higher in moderate shade versus full sun, and dark respiration was significantly higher in full sun than in moderate shade. Scotch broom was tentatively classified by the authors as shade intolerant, although further tests are needed for this to be definitive [146].

Individual life span/stand longevity:

Estimates of Scotch broom's life span range from 10 to 15 years in its native range [150], 15 years in communities in New Zealand [158], 17 years in California [15], and over 23 years at Barrington Tops, New South Wales, Australia [122]. Long-term studies in England found that Scotch broom plants kept free of insects grew larger and more quickly, and had lower death rates at 10 years than plants exposed to insects [150]. A comparative study of life expectancy between regions found mean maximum ages were 14.4, 12.8, and 14.4 years for New Zealand, Australia, and Europe, respectively. Death rates and the mean persistence of populations did not vary significantly (P>0.5) between native and nonnative populations. However, few of the Scotch broom populations examined in this study contained senescent individuals, so the maximum ages recorded do not necessarily indicate the maximum longevity of Scotch broom [91].

Smith (1994, as cited by [98]) outlined 4 growth stages of Scotch broom in Australia: Stage 1 comprises the first 2 years of age when seedlings establish in the spring. This stage is a period of high summer mortality and susceptibility to browsing by wildlife. Stage 2 covers the next 2 years and is characterized by rapid vertical growth (up to 6.5 feet (2 m)) and canopy establishment of a dense population of many young, erect plants. Reproductive activity usually begins by the time the plant is 3 years old. At Stage 3, plants are mature and are fully able to reproduce. Scotch broom typically forms dense stands with a nearly closed canopy, with branches leaning increasingly outwards as the plants age. Some dieback may occur in the lower, shaded branches. Stage 3 lasts from age 5 to about 9 years, with Scotch broom reaching its full height of 6 to 13 feet (2-4 m) before plants begin to lean and topple over. Stage 4 is characterized by an increasing number of prostrate, spreading branches, giving Scotch broom a leggy appearance. There is little or no establishment of Scotch broom seedlings during the latter stage, unless disturbance creates gaps in the broom canopy (Smith 1994, cited by [98]). These findings are supported by research in Washington [85] and New Zealand [158].

After Stage 4, Scotch broom stem density declines rapidly with stand age. Stems may become denuded of foliage and twigs, and eventually the plants may topple over and die. As the canopy of Scotch broom opens up, seeds falling from parent plants can grow and germinate, and in this way a stand of Scotch broom can perpetuate itself for many years, effectively excluding other vegetation. Scotch broom is said to retard the establishment and spread of many rare and endemic species in invaded Oregon white oak communities in the Pacific Northwest ([98] and references therein). Conversely, Williams [158] suggests that because Scotch broom leaves drop in late summer, and litter is sparse and readily decomposable, later successional species are able to establish and persist in broom stands.

Expansion of existing Scotch broom stands appears to be slow, having been measured as 6 to 13 feet (2-4 m) over a 7-year period at Barrington Top, Australia. Spread is more rapid in ungrazed open pasture, where it can reach 10 to 16 feet (3-5 m) a year ([60], and references therein).

SEASONAL DEVELOPMENT:
In California, Scotch broom seeds germinate from November to June inland, and January to July along the coast [17]. Typically, germination occurs after the 1st rains of fall (mid- to late-November) through the last rainfall of late spring (in early May) [14].

Vegetative growth slows in mid-summer but is compensated for by a very long growing season [97]. The period of most rapid vegetative growth is May to July, with some dieback occurring during seasonal drought periods. The period of dieback extends from mid-July to April with the largest decrease in biomass concurrent with the drought season between July and November. Scotch broom also shows a decrease in relative growth rate during its spring growth period as it matures, and the amount of dieback during the summer to fall period decreases with age [13]. Shoot biomass accretion in California foothills Scotch broom populations displayed a peak in the spring and a decrease during the summer [16]. On dry, hot sites, Scotch broom drops its leaves in late July or August [17]. Trifoliate leaves abscise in summer as new shoots emerge with small entire unifoliate leaves [78].

Flowers appear before leaves in Scotch broom. Bud burst and leaf flush may occur in early spring (February to March) in British Columbia, depending on elevation and climatic location [98]. Flowering dates reported for Scotch broom are as follows:

Place	Flowering dates
inland California	late March to April
coastal California	April-June [17,78]
Carolinas	April-May; May-July [105]

West Virginia	May-June [126]
Blue Ridge Province	April-May [160]
New England	May 26-June 27 [117]
northeastern U.S.	May, June [48]
coastal British Columbia	peak in May; slow blossoming as early as February [98]

Scotch broom seeds mature in June and July [17,78,98]. Seed dispersal occurs as pods dry on sunny days. Dispersal begins as early as mid-July in British Columbia [98] and can be quite extended, with the last seeds released in winter in Australia [60]. A 2nd flowering, following maturation of pods from the 1st flowering, is observed on some sites. Pods produced in the 2nd flowering typically produce fewer seeds [16,97], as do pods that mature later in the season of the 1st flowering [97].

Reduced shoot elongation [97] and nitrogenase activity [156] have been observed in Scotch broom during periods of seed production in mid-summer. Nitrogenase activity at one site was highest during early and late spring, coinciding with flowering and late fruit maturation, respectively. A decline in nitrogenase activity in early summer coincided with a period of drought [155].

Most photosynthate moves upward in the shrub toward branch tips during flowering, bud break, and seed set. Photosynthate starts moving down toward roots after seeds are "well grown" but before seed release (Bossard, unpublished data in [17]).

Timing and duration of various phenological events in Scotch broom, such as bud break, leaf fall and shoot elongation, varied with site elevation in a study in New Zealand. Scotch broom grew most of the year under adequate precipitation and a mild climate, and had 2 flowering periods at low altitudes [97].

Portuguese broom flowers in late March through May on the coast of California, and seeds mature in June and July. Drought conditions during summer cause growth to cease. Little dieback is observed during summer in a population in Marin County, probably because fog drip in late summer can be substantial. New growth resumes in winter and spring prior to flowering [4].

FIRE ECOLOGY

SPECIES: Cytisus scoparius, C. striatus

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations: Scotch broom sprouts from the stem after top-kill from fire [17,131,138] or mechanical removal [13,59]. Its ability to sprout seems to vary with season and severity of damage, although this relationship is unclear and deserves further investigation (see Fire Effects and Physical/mechanical control).

Several reports indicate a postfire flush of Scotch broom germination from the soil seed bank [17,86,98,139]. Several studies also indicate increased germination of Scotch broom seeds following heat treatments in the laboratory [14,108,122,131]. These results suggest that seeds of this species are well adapted to postfire germination.

Fire regimes:

There is no information available on the fire regimes in which the brooms evolved in their native range. However, Scotch broom and *Genista florida*,
a close relative of French broom, were early successional species following fire in their native range in Spain [53].

It is unclear how the presence of brooms may affect fire regimes in invaded communities. In general, in ecosystems where broom replaces plants similar to itself (in terms of fuel characteristics), brooms may alter fire intensity or slightly modify an existing fire regime. However, if broom invasion introduces novel fuel properties to the invaded ecosystem, they have the potential to alter fire behavior and potentially alter the fire regime (sensu [20,32]). A review of Scotch broom in Australia [89] suggests that presence of Scotch broom creates a fire hazard in forest areas in Australia and California, although the source of this assertion is not given. Where Scotch broom invades subalpine eucalypt woodland in Australia it forms a dense shrub layer, overtopping and depleting the grass layer, thus altering fuel structure such that fire intensities fueled by shrubs in the invaded community would likely be higher than those fueled by grasses in an uninvaded community [37]. Scotch broom invasions are also said to increase fire intensity and frequency in invaded Oregon white oak communities [23,139]. According to Tveten [139], where Scotch broom has invaded prairie and Oregon white oak woodlands on Fort Lewis in western Washington, it forms dense stands and increases fire hazard by creating extensive areas with large amounts of dead wood.

Scotch broom and Portuguese broom occur in a variety of ecosystems in North America that represent a range of historic fire regimes. In many areas where brooms occur, historic fire regimes have been dramatically altered due to fire exclusion and to massive disturbances associated with human settlement. The historic fire regimes of native communities in which brooms sometimes occur range from high frequency fires in grasslands to high frequency, low-severity fires in open ponderosa pine forests; and moderate frequency, high-severity fires in California chaparral. Brooms did not occur in these communities at a time when historic fire regimes were functioning, but has established since fire exclusion and habitat alteration began. It is unclear how historic fire regimes might affect broom populations.

It is also unclear how the use of fire to control broom in these communities might impact native species. Plant adaptations to fire are usually to a particular fire regime, or combination of fire frequency, intensity, extent, and season. When fire is used to control nonnative species, the frequency, intensity, and season of burning must be carefully chosen to avoid damaging native species. Prescribed fire may have undesirable effects if introduced into an ecosystem that has undergone shifts in species composition, structure, and fuel characteristics outside a natural range of variability in these attributes [1]. When the natural fire regime is altered, even highly fire-adapted plant communities may be vulnerable to competition from nonnative species [64].

According to Swezy and Odion [130], fire is an effective management tool for French broom, but is used primarily in mixed evergreen forest and grassland communities in California, where repeated annual burning for broom control "appears to have no unwanted side effects." Prescribed fire is used less frequently in chaparral communities where frequent burning or burning outside the natural fire season may have adverse effects on native communities.

Herbaceous communities dominated by nonnative annual grasses and forbs of Mediterranean origin occur throughout the Coast Ranges and foothills of the Cascade Range and the Sierra Nevada. A review by Keeley [64] indicates that much of the nonnative annual grassland in the Coast Ranges of central and southern California derives from a fire-induced type conversion of shrublands. The herbaceous communities that have long dominated these landscapes were largely created by anthropogenic burning by Native Americans, and were further maintained by intensive land use with fire and livestock grazing by European-Americans. In recent decades, however, grazing has been eliminated in some areas and anthropogenic fires reduced such that woody vegetation is reestablishing. Along with native shrubs, nonnative shrubs such as Scotch broom, French broom, and gorse colonize these sites. Nonnative shrub colonization of grasslands may decrease fire frequency but increase fuel loads and alter fire behavior ([64] and references therein).

In the Puget Trough of Washington and adjacent parts of British Columbia, native plant communities were once a mosaic of Oregon oak woodlands, wetlands, and fescue prairies. This mosaic is said to have been maintained by Native Americans who used fire to maintain conditions favorable to the growth of common camas and bracken fern (*Pteridium aquilinum*). These frequent fires removed shrubs and killed small Oregon oaks and Douglas-fir, maintaining a low density of woody species. A plethora of impacts following in the wake of Euro-American settlement, including fire suppression, grazing by livestock, introduction of nonnative species, landscape fragmentation, recreation, and other management impacts, have changed the structure and composition of these plant communities ([23,108,145] and references therein). Exclusion of fire from these communities has changed the regeneration pathways of Oregon white oak and increased densities of Douglas-fir, ponderosa pine, and understory shrubs. The natural vegetation associations of Oregon white oak are threatened by these interrelated conditions [1]. Scotch broom has become an important nonnative species in Oregon white oak habitats. It forms dense canopies 3 to 9 feet (1-3 m) tall, interfering with native species. Altered fuel structure and increased fuel loading result from invasion of Scotch broom and other nonnative species such as colonial bentgrass [23,135,138].

The relationship of Oregon white oak communities and fire is critical to any restoration effort [107]. If fire is used to reduce the occurrence and spread of Scotch broom in these ecosystems, consideration must be given to presettlement fire regime characteristics. Oak woodlands and associated prairies evolved with frequent, low-severity surface fires [1]. "Seasonal burning" in lowland prairies in Washington reportedly discourages Scotch broom invasion [109]. Spring burning on a 3- to 5-year rotation in Weir Prairie, Washington, causes little change in native prairie vegetation and maintains open Oregon white oak stands. Conversely, 50 years of annual burning in one area has eliminated Scotch broom and restricted Douglas-fir establishment, but has changed the native perennial bunchgrass prairies to introduced forb and annual grassland. On the other hand, fire suppression is more harmful to prairie vegetation than excessive burning, allowing Douglas-fir and Scotch broom to invade prairies and Oregon white oak woodlands. Closed stands of these species eliminate nearly all native prairie species. Sampled plots indicate that no native prairie species remained after 12 years of closed Scotch broom cover. Fall burning is recommended to remove Douglas-fir and Scotch broom from heavily infested areas, along with follow-up fires to kill dense Scotch broom postfire seedling establishment [139].

Reintroducing fire to these communities as a means of rehabilitation and restoration is complicated by the increased fuel loads associated with long-term fire exclusion and nonnative species invasion. On oak-prairie margins, fire used to control Scotch broom can pose risks to oaks unless it is used frequently enough to prevent excessive accretion of fuel [23]. High fire severities associated with high fuel loads increase mortality of Oregon white oak seedlings and saplings. Thysell and Carey [135] describe areas at Fort Lewis where mature oaks appear to have been killed by severe fire that was fueled by Scotch broom. Mechanical removal of Scotch broom and Douglas-fir before burning may reduce the potential for negative effects on oaks [23,135,138].

A single intense fire can reduce Scotch broom cover, but is likely to encourage germination of Scotch broom from the seed bank [17,86,98,139] and at least temporarily reduce cover of native perennials such as Idaho fescue. A second fire is necessary to kill broom seedlings within 2 to 3 years, before Scotch broom seedlings are reproductively mature (see Fire Management Considerations) [17]. Many native plants in these native communities thrive after a single low-severity fire, but may be adversely affected by repeated burning [1]. Additionally, nonnative species may be favored over native species if fire is too frequent [23,138]. Spot treatments using a flame thrower in the winter, when grasses are green and fire will not spread, can remove residual Scotch broom plants missed in previous fire treatments [1].

A prescribed fire program has been used to manage prairies and oak woodlands in some areas of Fort Lewis since the 1960s and 1970s. Fires are mostly set in February and March, and occasionally in the fall, on a 3 to 5 year rotation. The primary objective of the program is fuel reduction. While the program has been successful at maintaining some of the "best prairie and Oregon white oak woodland vegetation in western Washington," it has not completely stopped prairie encroachment by Douglas-fir and Scotch broom. Spring fires often fail to burn under dense Scotch broom or young Douglas-fir. So whenever possible, heavily invaded areas are burned under drier conditions than are open prairies. Even under drier conditions, however, spring fires often fail to burn through stands of dense Scotch broom or young Douglas-fir, leaving clusters of these species to reinvade burned areas [139].

The complex relationships among oak woodlands, wetlands, prairies, Douglas-fir forests, introduced nonnative plants, and intensively developed urban, suburban, and agricultural areas suggest that both a comprehensive set of conservation objectives and a comprehensive assessment of techniques for promoting indigenous species and techniques for controlling nonnative species are needed [23].

The following list provides fire return intervals for plant communities and ecosystems where Scotch and/or Portuguese broom may be important. It may not be inclusive. If you are interested in plant communities or ecosystems that are not listed, see the complete FEIS Fire Regime Table.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
silver fir-Douglas-fir	*Abies amabilis-Pseudotsuga menziesii* var. *menziesii*	> 200 [6]
California chaparral	*Adenostoma* and/or *Arctostaphylos* spp.	< 35 to < 100
California montane chaparral	*Ceanothus* and/or *Arctostaphylos* spp.	50-100 [94]
California steppe	*Festuca-Danthonia* spp.	< 35 [94,125]
western juniper	*Juniperus occidentalis*	20-70 [94]
jack pine	*Pinus banksiana*	<35 to 200 [38]
Jeffrey pine	*Pinus jeffreyi*	5-30
Pacific ponderosa pine*	*Pinus ponderosa* var. *ponderosa*	1-47 [6]
interior ponderosa pine*	*Pinus ponderosa* var. *scopulorum*	2-30 [6,8,68]
red-white-jack pine*	*Pinus resinosa-P. strobus-P. banksiana*	10-300 [38,52]
quaking aspen (west of the Great Plains)	*Populus tremuloides*	7-120 [6,50,74]
coastal Douglas-fir*	*Pseudotsuga menziesii* var. *menziesii*	40-240 [6,76,110]
California mixed evergreen	*Pseudotsuga menziesii* var. *menziesii-Lithocarpus densiflorus-Arbutus menziesii*	< 35
California oakwoods	*Quercus* spp.	< 35 [6]
oak-hickory	*Quercus-Carya* spp.	< 35 [148]
coast live oak	*Quercus agrifolia*	2-75 [49]
blue oak-foothills pine	*Quercus douglasii-P. sabiniana*	<35
Oregon white oak	*Quercus garryana*	< 35 [6]
California black oak	*Quercus kelloggii*	5-30 [94]
redwood	*Sequoia sempervirens*	5-200 [6,42,127]
elm-ash-cottonwood	*Ulmus-Fraxinus-Populus* spp.	< 35 to 200 [38,148]

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

POSTFIRE REGENERATION STRATEGY [124]:
Small shrub, adventitious bud/root crown
Ground residual colonizer (on-site, initial community)

FIRE EFFECTS

SPECIES: Cytisus scoparius, C. striatus

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

IMMEDIATE FIRE EFFECT ON PLANT:
As of this writing (2005) there is no fire-related information available in the literature for Portuguese broom. All of the information presented here comes from research on Scotch broom. Because of their similar reproductive

biology and ecology, it might be assumed that Portuguese broom will have a similar relationship to fire as Scotch broom, but more research is needed to test this assumption. Also see French broom in FEIS for more information from fire studies on this closely related species.

Fire top-kills Scotch broom, and high-severity fire causes complete mortality. Fire also causes some mortality in the soil seed bank [37]. However, field and laboratory studies indicate that heat from fires may either kill or scarify broom seed depending on temperatures reached and duration of heating (see details below).

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
The direct effects of fire on Scotch broom depend on fire severity. A study in Australia indicates that wildfire caused complete mortality in Scotch broom on 2 of 3 sites. The site judged to have experienced the lowest-severity burn was the only site where postfire sprouting of Scotch broom (from 3% of burned stumps) was observed [37].

Several reports indicate responses ranging from increased germination to mortality of Scotch broom seeds following heat treatments of increasing temperatures in the laboratory [14,108,122,131]. Field observations of Scotch broom seedling emergence following fire [17,86,98,111,139] support the contention that germination of Scotch broom seed is stimulated by heat from fire. Portuguese broom seeds also had increased germination rates following heat treatments [54].

Scotch broom seeds were heated in an oven at 150, 212, 300, and 390 °F (65, 100, 150, and 200 °C) for 1 to 2 minutes to simulate temperatures and durations measured at about 1 inch (2 cm) below the soil surface during a prescribed burn at El Dorado National Forest (Bossard unpublished, cited in [14]). Temperatures at or above 300 °F (150°C) for 2 minutes killed Scotch broom seed. Temperatures of 212 °F (100 °C) or more for 1 minute increased seed susceptibility to fungal pathogens; and temperatures of 150 °F (65 °C) for 2 minutes significantly ($P<0.05$) increased germination and did not decrease fungal resistance [14]. Scotch broom seeds, collected in France from plants that had been subjected to fire and had recovered, were heated in an oven to a range of temperatures from 120 to 300 °F (50-150 °C) and a range of exposure times from 1 to 15 minutes. No germination was observed at temperatures of 270 °F (130 °C) or higher when the exposure time was 5 minutes or more. However, moderate heat treatments at 160 and 212 °F (70 and 100 °C) significantly increased the rate of germination relative to controls. Scotch broom had higher germination rates following 5-minute exposure to 212 °F (100 °C) and 1 minute exposure to 270 °F (130 °C) than after mechanical scarification [131]. Similarly, tests on Portuguese broom seed collected in 1994 from a population in southern Spain that was last affected by fire in August 1970, were tested at treatment temperatures of 190, 250, 300 °F (90, 120, and 150 °C) for 1, 5, and 10 minute durations; and 120 °F (50 °C) for 10, 15, 30, and 60 minutes and 160 °F (70 °C) for 5, 10, 15, and 30 minutes. Heating at 190 °F (90 °C) for 5 and 10 minutes enhanced germination in Portuguese broom. Additionally, of the 7 legume species tested, Portuguese broom had the highest heat resistance with 76 $\pm$ 8.48% germination after heating at 250 °F (120 °C) for 10 minutes, and 2% germination after heating at 300 °F (150 °C) for 10 minutes. Mechanical scarification and hot water treatment also significantly ($p<0.05$) increased germination rates of Portuguese broom seeds over those of untreated controls. Seeds treated at 120 and 160 °F (50 and 70°C) at all durations, and at 190 and 250 °F (90 and 120 °C) for 1 minute did not have germination rates significantly different from controls [54].

In another laboratory study, Oregon white oak and Scotch broom were planted together in 1) pots containing soil that had been heated to 140 °F (60 °C) for 10 minutes before planting; 2) pots with about 1 inch (2 cm) of ash added to the top of the potted soils; and 3) control pots with no treatment. Scotch broom stem count was significantly ($p<0.001$) less than the control with the addition of ash and significantly greater than the control in heated soil. Heating the soil and adding ash significantly increased the mean stem count of Scotch broom above the control but was both significantly greater than the ash treatment alone, and significantly less than the heat treatment alone. Results suggest that the heat generated by prescribed burning would likely increase germination of Scotch broom, and that ash would reduce germination of all seedlings tested, but would have the least effect on Scotch broom [107,108]. Stem densities per pot were [107]:

	All species*	Scotch broom
Ash	8.5	4.0

No ash	49.5	10.5
Heat	33.5	11.0
No heat	49.5	3.5

* Stem density of all species includes Scotch broom and other oak-competitor plants (not oak seedlings)

Field studies support the contention that heat from low- to moderate-severity fire stimulates germination in Scotch broom seeds in the soil seed bank. Robertson and others [111] recorded seedling emergence for 3 years after a prescribed fire in subalpine snowgum (*Eucalyptus pauciflora*) woodland in Australia. They found 60 to 280 seedlings per 100 m^2
in burned plots 12 months after burning, and no seedling emergence in unburned plots. There was almost no seedling emergence in either burned or unburned plots 2 and 3 years after burning [111].

A comparison of postfire seed banks and seedling densities at 3 sites in Australia showed reductions in seed bank density after fire. A correspondence between fire intensity (generally, height of crown scorch) and soil seed bank reduction was not consistently observed [37]:

Site	Burn condition	Time since fire (months)	Viable seeds/m^2 in seed bank	Seed bank reduction as % of prefire seed bank	Total seedlings/m^2	Seedlings as % of prefire seed bank
Majors Creek	Unburned	6	28,377	n/a	6,620	19
		12	18,814	n/a	61	0.4
	Low intensity	6	1,862	93	699	27
	Medium intensity	6	699	97	626	47
	High intensity	6	3,117	89	692	18
		12	688	98	484	13
Barrington Tops	Prefire	-4	1,756	n/a	----	----
	Prefire	-2	1,117	n/a	----	----
	Very low intensity	12	482	57	103	18
'The Lanes'	Control burn	21	2,482	----	1,486	37
	Low intensity*	58	1,470	----	261	15

*data from [111]

Some postfire seed bank depletion can be attributed to germination, and on 2 of 3 burned sites, seedling density was proportionately higher in burned plots than in unburned plots 6 months after fire, suggesting that seeds may be scarified by fire. Seedling density was not higher after fire on the high severity site [37].

Variation in seed bank depletion following fire is influenced by several factors, including the initial size of the Scotch broom seed bank relative to that of native species, as well as interactions of fire severity and soil moisture content and their effect on heat penetration into the soil and duration of heating. Soil temperatures during fire do not exceed 212 °F (100 °C) until soil water is vaporized, while fire over dry soil can produce temperatures of several hundred °C in the top few centimeters of soil, where the majority of broom seeds are present. Soil moisture was very low when the wildfire burned at Majors Creek, whereas fires conducted at 'The Lanes' were conducted the day following rain. During 10 years of using fire to control Scotch broom at Barrington Tops, it was concluded that

Scotch broom reduction would be maximized during the hottest, driest months ([37] and references therein).

These results suggest that broom seeds are adapted to postfire germination. Thus, prescribed burning in areas infested with broom could increase germination and decrease seed bank density at the soil surface, depending on duration of temperatures reached during the fire. Changes in soil temperature could also play a key role in the flush of new germinating seeds when established plants are removed. Increased solar radiation could heat the soil and stimulate seed germination [35].

PLANT RESPONSE TO FIRE:
Observations indicate that Scotch broom regenerates after fire by seedling establishment and by stump-sprouting [17,37,109,111,131,138]. Several studies [37,98,111,139] indicate postfire germination of Scotch broom from the soil seed bank after fire (see Discussion and Qualification of Fire Effect). "Weedy outbreaks" of Scotch broom have been linked to fire in Australia [91].

Minimal sprouting occurs from cut Scotch broom plants, especially when cut at ground level during or prior to periods of moisture stress (Miller 1992b, cited by [98]) [104,144]. Saw cutting at the end of the summer drought period in the Sierra Nevada (August-October) resulted in a sprouting rate of less than 7%, whereas cutting at other times resulted in sprouting rates of 40% to 100% [13]. Conversely, a study in British Columbia found no difference in rate of sprouting between Scotch broom plants cut at the base in May versus July, with about 3% to 9% of cut plants sprouting overall. These sprouts died within 1 year [143,144].

A study in Oregon white oak savanna in southwestern British Columbia found that Scotch broom cover increased with disturbance, suggesting the possibility of a postfire increase in cover. Study plots established on both deep and shallow soils were burned, mowed, or weeded (selective nonnative species removals) to examine the effects of disturbance on the dynamics of native and nonnative flora. Scotch broom percent cover increased from 3.5% to 12.8% on deep soil sites, and from 0.7% to 3% on shallow soil sites in response to disturbance (averaged over all treatments) [70]. Whether the increase was due to sprouting or seedling establishment was not stated in the report.

Robertson and others [111] monitored postfire growth of Scotch broom seedlings for 4 years following fire. In 4 years, seedlings averaged over 3.3 feet (1 m) tall, and about 25% of the population had begun to produce seed. None of the 1- to 3-year-old seedlings produced seed [111].

A study of the effects of land-use history on postfire succession in Spain found no differences among past land-use types when vegetation was sampled 5 years after a wildfire burned across areas that were cultivated, abandoned and dominated by shrubs, or maritime pine (*Pinus pinaster*) woodlands. Postfire vegetation in all areas was dominated by Portuguese and white spanishbroom (*Cytisus multiflorus*), regardless of prefire vegetation or land-use history. Shrub cover dominated for at least 10 years after fire [96].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
The degree of postfire sprouting in Scotch broom is variable [37,111,139], and may depend on a number of factors including fire severity, site conditions, season and frequency of burning, plant age, and postfire site conditions. These aspects of broom fire ecology deserve further investigation.

At Weir Prairie on Fort Lewis Military Reservation, the effects of burn season on area burned, Scotch broom stem density, percent cover of Scotch broom, Scotch broom basal sprouting, Scotch broom mortality, and Scotch broom seedling density were tested. Trials were carried out in Oregon white oak woodland with an invading Scotch broom understory. The site had been managed with a 3- to 5-year spring prescribed fire rotation. All recorded Scotch broom were over 3.3 feet (1m) tall, except for seedlings. Initial (1994) and final (1995) surveys were performed in May. Results were as follows [139]:

Treatment	Unburned	Fall burned	Spring burned
Area burned (%)	N/A	90	78
Scotch broom stem density (number/m²)	47.8//109.3*	52.9//11.4	58.2//51

Cover (%)	20.0//48.4	24.8//3.5	13.8//12.0
Basal sprouting (%)	0	1.8	30.8
Mortality (%)	1.8	87	47.2
Seedling density (%)	5.9//5.5	8.2//5.9	6.3//3.0

*(1994//1995)

All fires in this study favored native prairie and Oregon white oak woodland species by killing Douglas-fir and Scotch broom, regardless of fire season. A period of aggressive mechanical or chemical removal of these plants could supplement prescribed burning and help restore prairies and woodlands, after which a program of both fall and spring prescribed burning can effectively maintain these communities (see Fire Ecology) [139].

Parker [86] suggests that response of Scotch broom populations to disturbance may be scale-dependent, and that care should be taken if extrapolating these results to landscape-scale disturbances. In studies of Scotch broom seed germination in Washington prairies, disturbance did not increase Scotch broom establishment. Undisturbed plots with the cryptogammic layer intact produced more seedlings than burned or scraped plots. A comparison of plots where seeds were added before burning versus after burning did suggest a positive (but not significant) effect of burning on Scotch broom seed germination itself. Burning did not, however, result in higher numbers of seedlings than unburned controls. For germinated seedlings, mortality through the dry season (June through August) was not significantly (P>0.2) different among surface treatments, nor did survivorship depend on density, with the result that initial differences in germination among the treatments persisted [86]. In previous work the author found that germination rates of Scotch broom were very high in these prairies relative to anthropogenically disturbed urban fields [85].

FIRE MANAGEMENT CONSIDERATIONS:

Postfire colonization potential:

There is very little information on the postfire colonization potential of either Scotch broom or Portuguese broom. However, due to their ability to sprout following aboveground damage, and to the scarifying effects of heat on their seed, wherever brooms are or have been present in or adjacent to burned areas, managers should expect brooms to establish and/or spread in the postfire environment.

Use of fire to restore Oregon white oak woodlands in Washington may promote establishment and spread of Scotch broom especially on marginal sites, although this relationship is not entirely clear [108].

Fire as a control agent:

Prescribed fire has been used in programs to control brooms and common gorse in Australia and New Zealand (e.g. [37,111]) and in North America (e.g. [18]) for many years with varied results. The successful use of fire to control broom species depends on the condition of the invaded community and the fire regime to which those native species are adapted (see Fire Ecology). Although a single prescribed fire can substantially reduce Scotch broom cover, follow-up treatment is needed to treat seedlings that emerge from the soil seed bank after fire. Agee [1] recommends a 2nd, "less intense" fire 2 to 3 years later, before Scotch broom seedlings begin to flower. Spot treatment, such as using a flamethrower in the winter, can remove remaining Scotch broom seedlings [1]. Repeated prescribed fire has been used to control French broom and associated Scotch broom in many locations in California for several years. Prescribed fire has also been used extensively on Fort Lewis Military Reservation in the Puget Trough of Washington to remove invading woody species (including Scotch broom) and maintain native species in Oregon white oak woodlands and Idaho fescue prairies, with mixed success [23,135,138]. Fire is also used to control Scotch broom in Australia and New Zealand (e.g. [37]). There are no reports on the use of fire to control Portuguese broom. Prescribed fire is effective in reducing the broom seed bank through direct mortality and stimulation of germination, and can be used to treat dense monocultures. A flame thrower or propane torch can be used for spot treatment of individual plants [161].

Fire alone cannot control Scotch broom, but if used as part of an integrated strategy it can be effective. As fire is the only method that can directly remove broom stands and deplete the soil seed bank, it can provide a window to manage Scotch broom before the stand regenerates [37]. When prescribed fire is used to stimulate Scotch broom germination from the seed bank, follow-up treatments such as subsequent controlled burns, spot burning, revegetation with fast growing native species, herbicide treatments, grazing, and hand-pulling can be used to kill seedlings and thus reduce the seed bank [17,37,111,161]. Selection of postfire strategies is important in enabling native species to establish and recover [111].

Timing prescribed fire appropriately can optimize results and minimize follow-up treatments. When areas are burned in summer, emerging seedlings are likely to be exposed to harsh, dry conditions, increasing likelihood of seedling mortality [161]. Additionally, Scotch broom is least likely to sprout if top-growth is removed in mid-summer [144]. However, permitting considerations may not allow for prescribed fires during this season.

Prescribed burning is most successful for controlling brooms when desirable vegetation establishes after fire. For example in Australia, Scotch broom seedling survival is reduced by grass cover, which can be encouraged by selective postfire treatments [37]. According to Keeley and Fotheringham [65], prescribed burning for restoration of North American mediterranean shrublands may be useful if accompanied by vigorous revegetation with native shrubs and herbs. In general, however, there are few places where fire-dependent shrublands are threatened by lack of fire, and few instances where prescribed burning is needed for natural resource benefits; it is most often used for fire hazard reduction. Negative impacts may arise from prescribed burning and fuel manipulations such as fuel breaks, which are potential corridors for nonnative species invasions into wildland areas [65]. While repeated prescribed burning is capable of substantially reducing cover and seed banks of brooms, they are invariably replaced with nonnative annuals (D'Antonio, personal communication in [64]).

Repeated prescribed burns are conducted in dense broom stands in invaded prairies and Oregon oak woodlands in Washington to reduce frequency and density of Scotch broom. In order to be effective, prescribed fire must be applied frequently enough to prevent fuel buildup, which threatens Oregon oak overstories, but not so frequently that nonnative herbaceous species are favored over native species [135,138]. In a study at Fort Lewis, Scotch broom cover averaged 61.6% before burning in September 1994 and March 1995. The September fire burned more of the stand, caused significantly (P=0.05) greater mortality, and resulted in significantly less sprouting than the spring fire. The fall fire resulted in significantly less density and cover of mature broom plants and had no effect on seedling density. The patchy spring fire significantly reduced postfire seedling density, but had no other significant effects. The authors concluded that several cycles of prescribed fire would be required to "restore the balanced fire regime" to Fort Lewis prairies [138].

Some fire preparation methods include cutting the shrubs, leaving the slash on site, and allowing it to cure before burning. This method allows for a higher severity fire than burning uncut stands, possibly resulting in greater mortality of shrubs and seeds. Follow-up treatment of sprouts and seedlings is still important. For example, early work on Scotch broom control in a subalpine habitat in Australia in the late 1970s employed hand-slashing of broom, heaping the slash over the site, and burning it when dry to improve effectiveness and of the burn. With "high-intensity" fire, a "very good" kill was achieved, and some seed was incinerated. Emergence from the remaining seed in the seed bank resulted in high seedling densities within 12 months. The control program was unsuccessful, however, due to logistical constraints that precluded follow-up treatments [25]. The most effective removal treatment of Scotch broom on the El Dorado Forest in the Sierra Nevada foothills was cutting shrubs in September and October, allowing cut shrubs to dry on site, and then burning dried shrubs in late May and early June. This killed sprouts and most of the seed within the top 1 inch (2.5 cm) of soil. Seeds within 1.6 inches (2 cm) of the soil surface were scarified by heat, germinated within 2 weeks, and died during the summer drought period. This reduced the amount of seed in the soil by 97%, and although some seed remained below 2 inches (5 cm) in ant nests, the reduction in the seed bank decreased the need for chemical or hand removal of new seedlings in succeeding years. Follow-up monitoring and treatment using this same combination of methods in a coastal area of Redwood National Park reduced the seed bank by only 52% and did not substantially reduce the time spent in follow-up control. The moister climate decreased the efficacy of this removal combination at Redwood National Park ([17], and references therein). Burning uncut Scotch broom is used with some success on Angel Island, California. Reburning the removal site is usually necessary 2 and 4 years after the initial burn (Boyd, personal communication in [17]).

A better understanding of fire severity requirements in relation to soil conditions and moisture regimes is needed to develop a fire management strategy that both removes broom stands and depletes the broom seed bank. Follow-up treatments are required for an extended period as broom seed banks are depleted slowly over time. In some cases, wildfire may provide a window of opportunity for broom management.

A weed flamer device can be used as a spot treatment to heat-girdle the lower stems of broom; this technique can be used in sensitive areas or at sites with insufficient fuel loads [161].

Fire hazard potential:

The available literature does not provide a clear picture on the potential fire hazard of broom stands. Several reviews (e.g. [17,35,89,149,161]) indicate that dense broom stands are a fire hazard (also see Fire Ecology). Furthermore, descriptions of the structure and composition of Scotch broom monocultures (see Growth form and stand structure) support the contention that dense, mature stands of broom could be highly flammable. Specifically, as Scotch broom stands age, the ratio of woody to green material also increases, and dead wood accumulates [150]. Scotch broom's frequent location on steep slopes adds to its fire hazard potential [161].

In spite of substantial evidence for the fire hazard potential of broom stands, researchers in California found uncut, mature and young stands of French broom difficult to burn, despite high temperatures and low humidities [79]. It is unclear what combination of variables is needed for complete combustion of broom stands.

MANAGEMENT CONSIDERATIONS

SPECIES: Cytisus scoparius, C. striatus

Scotch broom infestation
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IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Mule deer, elk, and black-tailed jackrabbits were observed browsing on Scotch broom at 2 California sites (mule deer and elk at one site, mule deer and black-tailed jackrabbits at the other) [13,16]. On a prairie site among redwood forest habitat, mountain quail, blue grouse, and harvest mice are known to eat Scotch broom seed [11]. Scotch broom seeds were also eaten by mountain quail in the southwestern Cascade Range of Oregon [102].

Scotch broom supports a rich insect fauna in England where it is native. Prior to introduction of insects for biological control of Scotch broom, a survey of insect fauna on Scotch broom at several sites in California and British Columbia found relatively fewer total insects, less diversity of species, and a total absence of seed and pod insects compared with Scotch broom in England. Larger numbers of 2 species were found on some sites. Observations suggest that this may be due to lack of herbivory of brooms in North America [149]. Even after the introduction of biological control agents, no substantial vertebrate or invertebrate herbivory was found at any life stage of a California foothills population; however, vertebrate herbivory significantly ($p<0.05$) decreased biomass of Scotch broom on a northern coastal site [13].

Several species of ant eat elaiosomes of Scotch broom seed, and thus aid in seed dispersal, with varying numbers and species at different sites [11].

Palatability/nutritional value:

A review from Australia suggests that Scotch broom seeds and mature shoots are unpalatable and even toxic to ungulates. Shoots are not used for forage except by rabbits in the seedling stage [89]. The source of this information is not given. A field experiment in New Zealand found that broom was moderately preferred by domestic goats and sheep in comparison to 5 other leguminous shrubs and forbs, 3 nonleguminous species, and 2 grasses [81].

An examination of the chemical composition of various browse species in New Zealand indicates that Scotch broom has high potential as a browse species for domestic goats and sheep. Nitrogen and element concentrations in leaf and stem material are presented here [67]:

Plant part	N*	P	K	S	Ca	Mg	Na	Cu	Fe	Mn	Zn	Si
leaf	3.9	0.16	1.1	0.19	0.49	0.16	0.04	23.3	181	581	54	5.2
stem	2.0	0.11	1.1	0.12	0.20	0.10	0.04	10.0	96	131	42	15.1

*Units are % dry matter for macro-elements (N, P, K, S, Ca, Mg, Na) and mg/kg dry matter for micro-elements

Researchers in Spain indicate that Scotch broom may represent a high quality food source for grazing ruminants, particularly during the dry season. Chemical composition (g/kg dry matter) of leaves, stems, flowers, and fruits of Scotch broom at different maturity stages are presented below. Plant material was collected from upland sites in northwest Spain [5].

Plant part	Collection date	Organic matter	Crude protein	Neutral-detergent fiber	Acid-detergent fiber	Acid-detergent lignin	Acetyl bromide lignin[a]	Ether extract
Leaves	19 May	944	277	220	150	28	84	7
	10 June	940	290	228	154	40	108	7
	9 July	946	221	280	147	53	143	8
	10 Aug	940	164	299	157	58	147	16
	15 Sept	944	171	288	145	54	133	13
Stems	19 May	942	242	267	159	39	86	7
	10 June	951	214	436	273	59	90	9
	9 July	968	191	487	324	98	121	18
	10 Aug	976	159	583	424	150	126	16
	15 Sept	979	145	561	375	133	125	17
	22 Oct	981	139	519	324	126	116	19
	26 Nov	980	156	473	337	139	138	23
Flowers	19 May	956	216	257	157	58	83	30
Fruits	10 June	963	181	393	220	33	143	7
	9 July	972	126	584	357	96	169	6

[a]Ferulic acid equivalents/kg dry matter

In-vitro digestibility and extent of degradation in different plant parts averaged across sampling dates is presented below. In general digestibility was highest at the first sampling date (May) and tended to decrease with later sampling dates [5].

Plant part	Apparent in-vitro digestibility (g/g dry matter)	True in-vitro digestibility (g/g dry matter)	Extent of degradation (g/g dry matter)
Leaves	0.825	0.873	0.541
Stems	0.699	0.757	0.396
Flowers	0.872	0.923	0.625
Fruit	0.584	0.685	0.386

Cover value: No information is available on this topic.

OTHER USES:
Information gleaned from literature reviews indicates that Scotch broom has been used as a substitute for hops, capers, and coffee, for tanning, and as a source of yellow dye. It has been used for medicinal purposes such as treatment of cardiac arrhythmia, as a diruetic, emetic, and purgative, as a cure for dropsy and respiratory problems, and to induce abortions. Branches were made into brooms and used for thatching, and the bark stripped to make rope [89].

Boom species are still widely sold as ornamentals in North America and Australia [60], and apparently harvested for ornamental floral greens in some Inland Pacific Northwest forests [114].

Scotch broom has been used to stabilize sand dunes and to bind soil in road cuttings [89,98]. Scotch broom was recommended as recently as 1979 for revegetation of exposed coastal sites in North America due to its ability to fix nitrogen and its resistance to toxic salt spray [136]. Although broom is considered a forestry pest in India, it has also been used in that country as a nurse crop for commercial trees [60].

IMPACTS AND CONTROL:
Impacts: Rankings - Portuguese broom is listed by the California Invasive Plant Council as one of the most invasive wildland pest plants with regional distribution in California, and Scotch broom is listed as one of the most invasive wildland pest plants with widespread distribution in the state [22]. Scotch broom is considered a "serious, documented threat to sensitive species or ecosystems" especially in the South Coast, Central Coast, North Coast, and Sierra Nevada bioregions [39]. Scotch broom is classified as a "Category 3," widespread, nonnative species by the USDA, Forest Service, Eastern Region. These plants are often restricted to disturbed ground, and are not especially invasive in undisturbed natural habitats [140].

Little information is available in the literature regarding impacts of Portuguese broom invasion. A review by Alvarez [4] indicates that it displaces native herbaceous and woody plant species, its seeds are toxic to ungulates, and mature shoots are unpalatable [4]. Impacts of Scotch broom invasion are suggested or described by several authors. These include interference with native plants and animals, interference with desirable species in forest plantations, and impacts on soil properties and processes. Scotch broom invasion may also increase fire hazard under some conditions, although the details of these conditions are not entirely clear (see Fire hazard potential). Additionally, Scotch broom invasion along roadsides causes problems and economic impacts for road maintenance crews [62].

Scotch broom invasion displaces native plant species including many threatened and endangered species (see Habitat types and Plant Communities). Scotch broom can dominate a plant community, forming a dense monospecific stand (see Growth habit and stand structure). Conditions under broom thickets are shaded and more humid than uninvaded stands and most understory vegetation dies out beneath large, mature broom shrubs ([60] and references therein), which leads to loss of herbaceous plants and tree seedlings on sites where broom is abundant [122]. In a cutover Douglas-fir forest in British Columbia, a 71% reduction in photosynthetically active radiation was measured under Scotch broom stands [103]. In an invaded prairie at Fort Lewis, Washington, a dense stand of mature Scotch broom intercepted 96% of the incident light and all native prairie vegetation was absent under these stands except colonial bentgrass and nonvascular cryptogams [139]. Scotch broom invasion in Australia appears to permanently change the structure, floristic composition and ecology of woodlands at one site

[60].

Scotch broom is a major forestry problem in the U.S., Canada, and New Zealand, particularly in reforestation after logging, as it can quickly overtop commercial crop trees ([60,98] and references therein). Scotch broom establishment after logging interferes with conifer establishment in the Douglas-fir region [31,62,103]. Scotch broom may occupy 90% canopy cover and intercept 65% of the intermittent light in Douglas-fir plantations. In Oregon and Washington, there have been complete stand failures of Douglas-fir regeneration because of Scotch broom infestations ([98] and references therein). Studies in Monterey pine (*Pinus radiata*) plantations in New Zealand suggest that Scotch broom competes with Monterey pine for light and water, reducing growth and biomass of the trees and affecting their resource allocation [152,153].

Scotch broom invasions may also impact native insects and animals. For example, Wilson and Carey [159] found a negative relationship between Scotch broom and deer mice, suggesting that Scotch broom areas have diminished value as wildlife habitat in the Oregon while oak communities in the Puget Trough, Washington. The small areas of remaining Oregon silverspot and Fender blue butterfly habitat have been invaded by Scotch broom and other nonnative species, changing plant community composition and structure and adversely affecting the quality of habitat for the threatened butterflies [99]. See Habitat Types and Plant Communities for more information on impacted species.

Broom invasion may also impact soils in invaded habitats. According to Bossard [17], Scotch broom "tends to acidify the soil," although the source of this assertion is not given. Results present by Haubensak and others [51] suggest that invasion by brooms (Scotch broom or French broom) can increase the total amount of nitrogen and the way in which nitrogen cycles in invaded ecosystems. Scotch broom is capable of fixing nitrogen throughout the year in regions with mild winters [156]. Nitrogen enrichment is unlikely to benefit native plants and may reduce species diversity in ecosystems where nitrogen-fixers are rare, although this has not been tested with regard to invasions by Scotch or Portuguese broom [33,51].

There have been reports of livestock loss due to ingestion of toxic quinolizidine alkaloids produced by Scotch broom. Human consumption of flowers and seeds of Scotch broom and related species results in nausea and vomiting [83]. Scotch broom is listed as an unsafe herb by the U.S. Federal Drug Administration (1993) [98].

Control: Scotch broom is difficult to control because of its substantial and long-lived seed bank [17]. The best method for removal of a Scotch broom infestation depends on the climate and topography of the site, the age and size of the infestation, the relative importance of impact to nontarget species, and the type and quantity of resources available to remove and control broom at a given site. All methods require appropriate timing and follow-up monitoring [17].

Portuguese broom is difficult to remove because of the large size of individual plants, deep roots, and the long-lived seed bank. Removal should be followed by 5 years of monitoring and follow-up treatments to achieve control. With limited resources, it is particularly important to determine the primary direction in which the population is expanding and start removal efforts there. Prevent seed dispersal into uninvaded areas by removing widely dispersed individuals from the main population center. Focus on preventing seed set and dispersal from all mature individuals each season so that no net increase in the seed bank can occur [4].

This is a general review on control methods for Scotch broom and Portuguese broom, and includes information that may be applicable for better understanding of its fire ecology. Given their similar biology and lack of information on all but Scotch broom, much of this information is generalized to apply to all brooms. More research is needed, however, to understand how this information applies to Portuguese broom. The reader is referred to other reviews [4,17,59,59,104] and the Weed Control Method Handbook for more details on control methods.

Prevention:

The most effective method for managing invasive species is to prevent their establishment and spread. Some methods of prevention include limiting seed dispersal, containing local infestations, minimizing soil disturbances, detecting and eradicating weed introductions early, and establishing and encouraging desirable competitive plants [119].

Alternatives should be used for horticultural and landscape purposes. McClintock [73] indicates that there are several ornamental brooms that are not invasive. An effective step in preventing further introduction and spread of the weedy brooms may be in asking nurseries to carry only the nonweedy species of broom [73].

Integrated management:

Brooms are best controlled by an integrated vegetation management program including monitoring, prevention, biological control, uprooting, cutting, controlled burns, competitive planting, and spot treatments with herbicides as a last resort. The choice of specific methods, timing, and combinations depends on the site conditions and the nature of the infestation [161].

Hoshovsky [59] sites a personal communication with a manager who is controlling thickets of both broom and gorse on San Bruno Mountain in southern California, by mechanical disking followed by burning. Seedlings and sprouts are then spot treated with 2 applications of glyphosate. He reports that all phases and tools of the program are working well and native species are returning. See the broom ESA for more information [59].

Physical/mechanical:

A variety of mechanical controls has been used in the control of Scotch broom, with some methods having the undesired effect of actually increasing spread and growth [98]. Manual methods of broom removal, such as hand-pulling and removal with hand tools, have the benefit of being highly selective, thus allowing removal of weeds with minimal damage to surrounding desirable vegetation. Hoshovsky [59] suggests the Bradley method, as described by Fuller and Barbe [45], as a sensible approach to manual control of brooms. He also suggests some logistics for securing and managing volunteers for manual control programs. Manual removal must be repeated regularly, since broom seedlings continue to establish from the seed bank after removal of adult plants [59]. See the broom ESA [59] for more information. Physical and mechanical control methods applied to adult broom plants are often followed by sprouting from remaining root crowns or aboveground stems, and emergence of numerous broom seedlings [104]. Therefore follow-up monitoring and treatments are requires for several years.

Hand-pulling can sometimes remove broom seedlings or plants up to 5 feet (1.5 m) tall. It is most easily done in coarse-textured soil after rain, when the soil is moist and loose, so that the root system may be more easily removed and the chances of sprouting minimized. Plants should be pulled as soon as they are large enough to grasp but before they produce seeds [4,59]. Manual pulling is a successful and popular method of removal of young shrubs in urban and park areas. Pulling can disturb the soil, however, possibly damaging desirable species [98]. Hand-pulling controls Scotch broom on preserves in northwest Oregon [109].

Hand tools:

Small broom plants can be killed by hoeing, either by cutting off the tops, or by stirring the surface soil and exposing seedling roots. Care must be taken to avoid damage to roots of desirable vegetation. Broom plants with a large tap root may not be effectively removed by hoeing and are likely to sprout; a claw mattock is effective for removing plants up to 13 feet (4 m) tall. Hand digging may be more effective; however, it is suggested that any piece of root that breaks off and remains in the soil may produce a new plant. Additionally, digging disturbs the soil and may trigger germination and establishment from broom seeds in the soil seed bank [59].

Pulling with weed wrenches is effective for broom removal [4,17,137]. The wrench removes the entire mature shrub, eliminating sprouting from the stump. If broom is densely branched, long-handled loppers or a pruning saw can be used to remove the lower limbs before pulling shrubs [4]. Wrench removal is labor-intensive, but can be used in most kinds of terrain and allows targeting of broom plants with low impact on desirable species in the areas. However, the resultant soil disturbance tends to increase the depth of the broom seed bank, prolonging broom presence on the site [17]. Additionally, Ussery and Krannitz [144] found substantially more trampling of native species when adult broom plants were removed by pulling rather than cutting. Golden Gate National Recreation Area has "had success" using volunteers to remove broom with weed wrenches and then closely monitoring and removing broom seedlings for 5 to10 years [17].

Cutting:

Brush cutters, power saws, axes, machetes, loppers and clippers can be used to remove top growth. Cutting is best done before plants set seed. According to a review by Hoshovsky [59], about half of the remaining broom roots can be expected to sprout following this treatment. Several other authors (e.g. [4,98,104,109,144]), however, indicate minimal sprouting from cut Scotch broom plants, especially when cut down to ground level or below the soil surface during or prior to periods of moisture stress. Saw cutting at the end of the summer drought period in the Sierra Nevada (August-October) resulted in a sprouting rate of less than 7%, whereas cutting at other times resulted in sprouting rates of 40% to 100% [13]. For additional insurance against sprouting from cut stems, peel bark back to the ground, or split the stump into shreds with a hand axe. The Golden Gate National Recreation Area's Habitat Restoration Program has achieved 60% to 80% mortality of Portuguese broom by hand cutting alone during late summer and early fall in the Marin Headlands [4].

In Oregon white oak savannas on the southeastern tip of Vancouver Island, British Columbia, Ussery and Krannitz [143,144] compared the effectiveness of uprooting versus cutting of Scotch broom at the base as control methods for Scotch broom. They also compared the relative site disturbance of each method (disturbed soil, exposed soil, and trampled vegetation) during 2 different seasons (May, when the shrub was in flower, and July, just prior to seed dispersal). Greater numbers of Scotch broom seedlings emerged in plots where adult brooms were uprooted, although there was considerable variation within and between study sites. Sprouting was observed in only 2 of the 60 Scotch broom stems cut during broom removal, and there was no difference in rate of sprouting between plants cut in May and July. Uprooted plants did not sprout. Cutting resulted in less overall site disturbance than did uprooting. Trampling was higher in July than in May, but in July the trampled plants were nonnative grasses, whereas in May they were native common camas. The authors suggest that a preferred strategy for removal of Scotch broom from Oregon white oak savanna is to cut Scotch broom shrubs at the base after native herbaceous species have set and distributed seed. This approach will minimize damage to native vegetation and reduce the amount of broom seedling regeneration [143,144].

Other mechanical methods of broom removal such as power tools, bulldozers, and backhoes are less selective and more likely to damage associated vegetation, and are more effective on gentle topography with few obstacles. Dense patches of Scotch broom have been eliminated by bulldozing and repeated disc cultivations over 2 years [89]. Brush hogs, which twist off aboveground biomass, can be used for removal of aboveground broom biomass, and are more destructive to regenerating tissues than is clean cutting. However, depending on the season of treatment, sprouting can still be a problem [17]. Equipment operators should also be aware that seed-contaminated soil may become embedded in tools, tires, and machinery, and be transported to new, uninfested sites [98]. These methods are rarely appropriate for wildland settings, as they are likely to adversely impact native species and create conditions that favor soil erosion.

Brush cutters and chainsaws are also effective for removing Portuguese broom. However, where it is difficult to cut shrubs flush with the ground, sprouting is likely. Mowing has had mixed results on Portuguese broom [4].

Mulching with 3 to 4 inches (8-10 cm) of straw (certified weed-free) during winter or spring (before seedlings are over an inch tall) may prevent broom seedling emergence. A controlled study by the Habitat Restoration Team in California, demonstrated that mulching with rice straw was 99% effective in preventing French broom seedlings from emerging through straw throughout the germination period from December to April. Mulching also increased the mortality of brush-cut French broom in the same study when applied during winter (Alvarez unpublished data, cited by [4]).

Fire: See the Fire Management Considerations section of this summary.

Biological:

Biological control of invasive species has a long history, and there are many important considerations before the implementing a biological control program. Tu and others [137] provide general information and considerations for biological control of invasive species in their Weed Control Methods Handbook. Additionally, Cornell University, Texas A & M University, and NAPIS websites offer information on biological control.

Biological control of Scotch broom in North America began in 1960. Three insects were purposefully introduced as biological control agents, and numerous accidental introductions of natural enemies have also been reported. The insects purposely introduced include Scotch broom bruchid (*Bruchidius villosus*) [27], Scotch broom seed weevil (*Exapion fuscirostre*) [28], and Scotch broom twig miner (*Leucoptera spartifoliella*) [29]. The latter 2 species are specific to Scotch broom, while the former also attacks Portuguese broom, Spanish broom, and French broom. See Coombs and others [30] for more information on these insects, their distribution, and effects. Scotch broom is also unique in that it is heavily attacked by a number of native arthropods, particularly aphids and other sucking insects. Additionally, many Scotch broom plants in older infestations are dying due to a fungal pathogen suspected to be *Selenophoma juncea*, which is widespread and seems to be the most important mortality factor. This pathogen has not, however, been approved for distribution [30].

Experimental analysis by Parker [85] suggests that a seed-eating insect would need to reduce Scotch broom seed production by as much as 99.9% to halt population expansion in the fastest growing population and by 70% to stop population expansion in the slowest-growing population. In Australia, Sheppard and others [120] compared the impact of seed predators among nonnative pastures and native grasslands and suggested that a seed loss of 62% was sufficient to suppress Scotch broom in native grassland, whereas >97% seed loss was required for suppression in nonnative pasture.

Biological control agents have not been reported for Portuguese broom [4].

Use of "bioherbicides" whereby native pathogens are employed to control Scotch broom and gorse is being investigated [103].

Grazing:

Heavy grazing by domestic goats during the growing season for 4 to 5 years has been reported effective in New Zealand, and grazing by llamas has been tried at a few sites in California (Archbald, personal communication in [17]). A study in Australia indicates that domestic sheep had minimal impact on Scotch broom vigor in infested pastures. Goats had a major impact when Scotch broom density was low (4% ground cover) and no impact when broom density was at 10% cover. Goats also stripped bark from Scotch broom plants in winter. Both sheep and goats prevented seed production by eating stem and flowering points, and both ate new Scotch broom shoots in summer [58].

The disadvantage associated with using domestic goats is that they are not selective, and native species that start to revegetate the area are also eaten [17,60]. Because cattle do not graze broom, it is becoming an increasing problem in Australia in areas where cattle are the only grazing animals. In these areas broom stands increase in size and the pasture is covered with dense broom stands [60].

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 [21]. 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. See the Weed Control Methods Handbook [137] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals and adjuvants. Also see the broom ESA [59] and other reviews [60,89,98] for more detailed information on chemical control.

The main chemicals used to control broom are picloram, triclopyr, glyphosate, fluroxypyr and metsulfuron-methyl [60,89]. Foliar sprayed glyphosate has been used to kill mature Scotch broom plants [89]. The foliar spray impacts nontarget species, and Scotch broom sprouting may occur after spraying. Triclopyr ester applied to basal bark is also effective at killing Scotch broom (Bossard unpublished data in [17]). Both of these chemical methods should be used during periods of active growth after flower formation. Chemical removal alone results in standing dead biomass that makes monitoring for and treatment of broom seedlings difficult [17].

Herbicides have not been used on Portuguese broom in the Marin Headlands, and there are no published accounts of their use elsewhere, but the treatments used on Scotch broom are likely to be effective on Portuguese broom [4].

Killing large amounts of broom with herbicides may leave a large amount of standing dead biomass that may present a major fire hazard [17].

Cultural:

Sowing native plant species that have the potential to interfere with broom may be a preventive method of weed control. In some cases later successional plants may be encouraged to take root among the unwanted vegetation. Williams [158] suggested that broom stands provide a good environment for establishment of some native broadleaved shrubs and trees, and that these native seedlings should be looked for in broom stands, and encouraged. Williams also recommends that seeds of taller growing plants be sown among the broom, as they may eventually shade out the broom [158].

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