Ulex europaeus

INTRODUCTORY

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AUTHORSHIP AND CITATION:
Zouhar, Kris. 2005. Ulex europaeus. 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 26].

FEIS ABBREVIATION:
ULEEUR

SYNONYMS:
None

NRCS PLANT CODE [89]:
ULEU

COMMON NAMES:
gorse
common gorse
furze

whin

TAXONOMY:
The currently accepted name of gorse is *Ulex europaeus* L. (Fabaceae) [28,33,36,43,84].

LIFE FORM:
Shrub

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
Gorse is listed as a noxious weed in Washington, Oregon, California, Hawaii [43], and British Columbia [90]. See the Invaders database for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: Ulex europaeus

Sherry Ballard © California Academy of Sciences

GENERAL DISTRIBUTION:
Gorse is native to central and western Europe and the British Isles, where it is an important component of native heathland vegetation (see Habitat Types and Plant Communities) ([37,45,70] and references therein). Gorse also occurs on abandoned farm land and disturbed forests in parts of its native range ([70] and references therein).

Introduced to the eastern U.S. as an ornamental and hedge plant in the early 1800s, gorse established outside cultivation by 1900 [49,50]. It now occurs along the Atlantic coast from Virginia to Massachusetts. Gorse was introduced as an ornamental in Oregon in the late 19th century, and has since spread widely in coastal areas from California to British Columbia and on 2 Hawaiian islands ([15,26,32,37,70] and references therein). It has been reported in the northern Sierra Nevada foothills and in every coastal county in California, from Santa Cruz to Del Norte, although sparingly in southern California [33,37]. Plants database provides a state distribution map of gorse.

Gorse was introduced to Australia and New Zealand in the mid-19th century for domestic sheep forage and hedges, and by 1900 was declared a noxious weed in those countries. It now occurs in most temperate areas of the world, and is considered a weed in Chile, Iran, Italy, Poland, northwest Spain, and Tasmania ([32,37,45,70] and references therein). Much of the literature on the biology, ecology, and management of gorse comes from New Zealand.

The following lists include vegetation types in which gorse is known or thought to be potentially invasive, based on reported occurrence and biological tolerances to site conditions. Precise distribution information is limited, especially in eastern North America; therefore, these lists are not exhaustive.

ECOSYSTEMS [27]:
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES27 Redwood
FRES28 Western hardwoods
FRES34 Chaparral-mountain shrub
FRES42 Annual grasslands

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

CA	DE	HI	MA	NY	OR	PA	VA	WA	WV

CANADA

BC

BLM PHYSIOGRAPHIC REGIONS [4]:
1 Northern Pacific Border
2 Cascade Mountains
3 Southern Pacific Border
4 Sierra Mountains

KUCHLER [47] PLANT ASSOCIATIONS:
K002 Cedar-hemlock-Douglas-fir forest
K005 Mixed conifer forest
K006 Redwood forest
K010 Ponderosa shrub forest
K012 Douglas-fir 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

SAF COVER TYPES [23]:
229 Pacific Douglas-fir
230 Douglas-fir-western hemlock
232 Redwood
233 Oregon white oak
234 Douglas-fir-tanoak-Pacific madrone
243 Sierra Nevada mixed conifer

244 Pacific ponderosa pine-Douglas-fir
245 Pacific ponderosa pine
249 Canyon live oak
250 Blue oak-foothills pine
255 California coast live oak

SRM (RANGELAND) COVER TYPES [79]:
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

HABITAT TYPES AND PLANT COMMUNITIES:
In its native range on the western seaboard of continental Europe and the British Isles, gorse often occurs as a dominant species in various heathland plant communities [25,75]. Associated species in these Atlantic heathlands in France and Spain include dwarf gorse (*U. minor*), heather (*Calluna vulgaris*), several heath species (*Erica* spp.), Scotch broom (*Cytisus scoparius*), and hypnum moss (*Hypnum jutlandicum*) [29,93]. Gorse dominates shrubland communities in northwest Spain where associated species include heath, heather, and rock-rose (*Halimium alyssoides*), with minor amounts of herbaceous species such as bristle bent (*Agrostis curtisii*), and velvet bentgrass (*A. canina*) [65,80,82]. Gorse may also be associated with maritime pine (*Pinus pinaster*), bluegum eucalyptus (*Eucalyptus globulus*), shrubby blackberry (*Rubus fruticosus*), western brackenfern (*Pteridium aquilinum*), European chestnut (*Castanea sativa*), English oak (*Quercus robur*), and sycamore maple (*Acer pseudoplatanus*) [58]. On heathland in England, gorse is among several species (including birch (*Betula* spp.), Scots pine (*Pinus sylvestris*), bracken, and *Rhododendron ponticum*) invading sites formerly dominated by heather (20-50 years prior). Gorse is native here, but is invasive in lowland heaths [54]. Gorse occurs both as a minor component in successional stages dominated by other species, and as a dominant among native heathland species [55]. Heathlands consisting of bracken, gorse, and heather may also establish about 100 years after cultivation ceases [70].

Very little information is available describing habitats and plant communities invaded by gorse in North America. In **California**, gorse occurs in northern and coastal scrub communities and grasslands [9]. At the Golden Gate National Recreation Area gorse occurs with other nonnative shrubs including French broom (*Genista monspessulana*) and Scotch broom [86]. Gorse also occurs in redwood (*Sequoia sempervirens*) forests [76].

In **Oregon** gorse occurs along the coast and some parts of the interior. It occurs in early succession after fire or logging in Douglas-fir (*Pseudotsuga menziesii*) forests, along with Scotch broom, foxglove (*Digitalis* spp.), coastal burnweed (*Erechtites minima*), and common St. Johnswort (*Hypericum perforatum*) [38].

In **Washington** and southern **British Columbia**, gorse and Scotch broom infestations threaten Oregon white oak (*Quercus garryana*)-Pacific madrone (*Arbutus menziesii*) ecosystems. Ten percent of Vancouver Island is infested with gorse and Scotch broom, and there is concern that their dense thickets shade out native vegetation and limit growth of conifer seedlings [46,64]. In general, gorse forms a major component of the disturbed areas it occupies, potentially excluding rare species associated with Oregon white oak ecosystems such as Howell's triteleia (*Triteleiagrandiflora* var. *howellii*), golden paintbrush (*Castilleja levisecta*), and deltoid balsamroot (*Balsamorhiza deltoidea*) [12].

Gorse was introduced to **Hawaii** before 1910. It is now found primarily at high elevations, up to about 7,900 feet (2,400 m) with isolated pockets down to 1,500 feet (450 m) on southeastern slopes on Hawaii; and between 2,100 and 7,300 feet (630-2,220 m) on northwestern slopes on Maui. It forms dense, tall stands with as many as 60,000 stems/ha. Gorse is primarily a problem on grazing lands, but may also invade open upland forests and subalpine shrublands [17].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Ulex europaeus

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GENERAL BOTANICAL CHARACTERISTICS:
The following botanical description of gorse is based on information compiled from florae [28,33,36,63,84] and reviews [15,20,37,70], unless otherwise cited. It describes characteristics that may be relevant to fire ecology, and is not meant for identification. Keys for identification are available (e.g. [28,33,36]). Additionally, gorse resembles but is morphologically distinct from several invasive broom species that occur in similar habitats. DiTomaso [20] provides a table of characteristics to distinguish among broom species (*Cytisus* spp., *Genista monspessulana*, and *Spartium junceum*) and gorse.

Gorse is a medium to tall, densely branched, perennial shrub up to 16 feet (4.8 m) but usually less than 8 feet (2.5 m) tall in North America. Gorse is woody and evergreen. Twigs are hairy when young. On older plants rigid, strongly angled, intricately intertwined branches arise from the base and end in spiny tips. Seedlings are of variable morphology [53], though seedlings and young shoots near the ground have small alternate leaves with 3 leaflets. Leaves are reduced to scales or stiff spines, 1.8 to 2.6 inches (4.5-6.5 cm) long, on mature plants such that plants are densely covered with sharp spines. Gorse has persistent, pea-like flowers, up to 1 inch (2.5 cm) long. Flowers are usually borne singly in leaf axils or concentrated near branch tips on 2nd-year twigs. The fruit is a legume, 0.4 to 0.8 inch (1-2 cm) long, bearing a variable number of seeds (1 to 8). Gorse seeds bear elaiosomes [62].

The **root system** of gorse growing in a chalk heath in England was described as shallow, with the majority of roots occurring in the top 4 inches (10 cm) of soil, and a tap root growing to at least 12 inches

(30 cm) (Grubb and others 1969, as cited by [12,70]). Observations of gorse growing in New Zealand suggest that plants that have been repeatedly burned have a very dense network of roots, and when these plants are removed they can leave a hole up to 3 ft (1 m) across and 1.5 to 2 feet (46-60 cm) deep [5]. No description of a gorse root system growing in North America or in other substrates is available. However, according to reviews, gorse has an extensive, multi-branched lateral root system with nitrogen-fixing root nodules [15], and is supplemented by a fine mat of adventitious roots that descend from lower branches [37]. The source of this information is not given.

According to reviews, gorse has photosynthetic stem tissue [20], and photosynthesis occurs mainly in the epidermis of the stems and spines [15].

Growth form and stand structure: Some authors identify 2 variants or ecotypes of gorse in New Zealand as "short spine" gorse and typical or "wild" gorse. Short spine gorse has shorter spines and a denser bush than typical or wild gorse [48,59].

Other authors describe 2 ecotypes of gorse as prostrate and erect. Prostrate types occur in exposed, windy areas. Erect plants described in British Columbia attain heights of 7 to 10 feet (2-3 m), on average, with a crown diameter of up to 13 feet (4 m), and a maximum height of 16 feet (4.8 m). In areas with very dense vegetation, gorse generally produces a single main stem, and on more open sites grows multiple stems ([12] and references therein). In middle-aged stands in New Zealand, a mean canopy height of 13 feet (4 m), a maximum height of 23 feet (7 m), and a maximum diameter of 8.5 inches (21.7 cm) at 3 feet (1 m) aboveground were recorded (Lee and others 1986 as cited by [12]).

In areas where it is invasive, gorse is often described as growing in dense stands [5,13,22,24,32,39,64] and impenetrable thickets [26,63] that cover large areas and produce a substantial amount of aboveground biomass [20,21,22,64]. Mature gorse stands in New Zealand had stem densities of 60,000 stems/ha, and a mean basal area of 51 m^2/ha (Lee and others 1986 as cited by [12]). Similar stem densities have been observed in British Columbia [12].

Measurements in New Zealand indicate rapid biomass accumulation in gorse-dominated stands. On one site, gorse was the dominant species 10 years after fire and annual dry matter accumulation averaged 10,000-15,000 kg/ha. In older stands other species shared dominance with gorse and biomass accumulation slowed to 2,000 to 4,000 kg/ha/year [21]. In another area, where fire had burned a closed-canopy stand of gorse, postfire communities with greater than 80% cover of gorse averaged over 65,000 kg/ha 6.5 years after fire [22]. In 8-year-old gorse shrubland in northwest Spain with approximately 90% cover of gorse and mean height of vegetation about 4 feet (1.2 m), total biomass was about 5.4 kg/ha [80,82]. However, biomass can reach about 40,000 to 60,000 kg/ha with stratified layers of vegetation [82]. Relative amounts of woody to green material increase as gorse plants age [22,65] (see Fire hazard potential).

RAUNKIAER [68] LIFE FORM:
Phanerophyte
Chamaephyte

REGENERATION PROCESSES:
Gorse reproduces from seed and can sprout from stem tissue following damage to aboveground tissues. Its ability to sprout from roots is unclear (see Asexual regeneration).

Pollination: According to literature reviews, gorse is pollinated by bees and similar insects [12,97]. Gorse flowers lack nectar, but visiting insects trigger the explosive release of pollen ([12] and references therein).

Breeding system: No published research was found on this topic; however, a review by Clements and others [12] states that while gorse is self-compatible, outcrossing results in higher fertility.

Seed production: Gorse usually begins producing flowers within its 2nd or 3rd season of growth, although coppice growth may not flower for 3 or more years. Plants established by root cuttings can flower within 6 months of rooting ([12,97] and references therein). Gorse produces numerous flowers each year; however a large percentage of flowers fail to produce fruit. In British Columbia, this may be attributed partly to the fact that some flowering occurs in winter when there are no insects to disperse the pollen ([12] and references therein). The annual seed deposit was 500 to 600/m² under a dense stand of gorse on a site in New Zealand where the introduced seed weevil (*Exapion ulicis*) was established (see Biological control). Observations at this site indicate that some gorse plants seed profusely while others produce very little [39]. On another New Zealand site, where 6-year-old gorse plants averaged 4.3 feet (1.3 m) tall, seedfall under the canopy averaged 2,120 seeds/m²/year. Three feet (1 m) from the center of shrubs, seed density was less than 500 seeds/m², and was 85 seeds/m² eight feet (2.5 m) from the center. On plants infected with seed-feeding weevils, the number of seeds produced per bush was reduced to 45% of that produced by uninfected bushes [35].

Seed dispersal: Most gorse seeds fall directly beneath the parent plant, although some are dispersed through the action of the dehiscent pods, which can eject seeds up to 16 feet (5 m) from the parent plant (Moss 1959, as cited by [70]). Under 6-year-old gorse plants in New Zealand, 39.4% of seeds fell under the canopy, and 55.7% fell within 3 feet (1 m) of the center of the shrubs. Seed density was greatest at the canopy edge, with a consistent decline in seed density with distance from the shrub center. Very few seeds were collected 8 feet (2.4-2.5 m) from the center of the shrubs [35].

Gorse seed dispersal over intermediate distances may be attributable to insects, animals, and possibly wind gusts. Gorse seeds have elaiosomes that may stimulate secondary dispersal by ants [62], as was observed in England by Chater (1931, as cited by [20,70]). Gorse seeds may also be spread by birds ([12,70], and references therein). Johnson [42] observed gorse seedling establishment up to 160 feet (50 m) from where parent plants stood before fire. He suggests that seed may have been spread by wind gusts, based on observations of gorse's "flattened, winged pod" [42].

Long distance dispersal of gorse seed may occur via water transport in streams; transport along roads, especially on vehicles and equipment used in agriculture and logging; and transport by wildlife. The grinding action of stream bottom gravel may also serve to scarify water-transported seeds ([12,70], and references therein) (see Germination). Williams [94] found an average of 8 gorse seeds/m² in the top 4 inches (10 cm) of soil and 5 seeds/m² in the 4- to 8-inch (10 to 20 cm) depth along rivers in New Zealand.

Seed banking: Gorse seed accumulation in litter and soil has been measured by several researchers in New Zealand. Total number of seeds measured in the top 12 inches (30 cm) under gorse at 17 sites in New Zealand ranged from 133 to 20,742 seeds/m², with an average of 5,446 seeds/m². Over 90% of these seeds occurred in the top 2.4 inches (6 cm). Seed densities on 23 burned gorse sites ranged from 44 to 15,342 seeds/m², with about 88% in the top 2.4 inches (6 cm) on average [99]. At another site researchers measured an average of 2,660 seeds/m² in the top 4 inches (10 cm) of soil under gorse before burning and an average of 1,000 seeds/m² after burning. Seventy-one percent of seed occurred in the top inch (2.5 cm) before burning and 68% in the top inch (2.5 cm) after burning [74]. Ivens [39] measured 10,000 gorse seeds/m² in the top 6 inches (15 cm) of soil under gorse, with about half of the seeds occurring in the litter or upper inch (2.5 cm), and about 75% in the top 2 inches (5 cm). Seed densities were highly variable among the 6 sample plots. Partridge [60] found gorse seed in the soil seed bank (at densities up to 6,500 seeds per m²)at 4 sites in New Zealand, 3 of which (2 dominated by brackenfern, and 1 forested site) lacked gorse in aboveground vegetation [60].

Most gorse seed has a hard, impermeable seed coat, and typically requires scarification for germination (see Germination). This suggests a potential for persistence in the soil seed bank. Additionally, anecdotal and experimental evidence from the field suggest that gorse seed remains viable in the soil seed bank for several years. Several reviews cite the work of Moss (1959) (e.g., [34,70,97]), who recorded the following data following clearing of gorse from a site in New Zealand:

Time since gorse was cleared from site (years)	Mean number of gorse seeds/m² in top 2 inches (5 cm) soil
1 to 2	1,816
2 to 10	103
10 to 26	34

Gorse seed viability exceeded 85% in this study. Based on these data and similar observations it is suggested that gorse seed can lie dormant in the soil for 30 years or more [12,34,70,97]. The presence of gorse seed in the soil in the absence of parent plants suggests some degree of persistence; however, it is uncertain whether this seed persisted on site, or was carried there at a later date [34,70]. Zabkiewicz [97] cites a report that states that gorse seed can remain viable in the soil for 70 years; however, the source of this information is not given.

Hill and others [34] studied longevity of gorse seeds in bags buried 1 to 6 inches (2.5-15 cm) in the soil over 20 years at 3 sites in New Zealand. They found that gorse seed viability declined over time and that seed survived longer when buried deeper. Results varied among sites, but this study did not examine the relative importance of climatic conditions or genotype effects. At 2 of the sites the number of viable seeds buried at a depth of 2 inches (5 cm) declined to 10% of the original number within 10 years and to 1% within 20 years. At the 3rd site, almost all seeds recovered from the soil were viable, and losses from the seed bank were probably due to germination [34].

A large proportion of gorse seeds recovered from the soil are viable [60,74,99]. When gorse occurs on or near a site, or has previously occurred there but been removed, managers must be alert to the possibility that gorse seedlings may establish from seed in the soil following soil or vegetation disturbance. For example, when plantation pine forests in New Zealand are harvested after 25 to 35 years, soil disturbance often results in germination of buried gores seeds, even though gorse may have been absent from the plantation for 15 years or more [34].

Germination: Because a large percentage of gorse seeds have a hard, impermeable seed coat, germination rates are highly variable without pretreatment, ranging from 0 to 90%. Gorse seed placed in boiling water for 30 seconds and then cooled quickly under tap water, resulted in mean germination percentages of 96%, 94%, and 90% [53]. Similarly, gorse seed taken from the soil and scarified with sandpaper had germination rates of 73% on average [74], while gorse seed with its seed coat removed with a scalpel had germination rates typically exceeding 90% [99]. Hard-seededness is greatest when seed is first shed and progressively declines as the seed lies on the soil surface and becomes incorporated into the soil [41].

Germination rates under a gorse canopy differ substantially from those that occur following removal of plants by physical disturbance (e.g. cutting), fire, or chemical control. Observations indicate a flush of gorse germination following herbicide kill and bulldozer removal of gorse [5], cutting [39], and fire [73,74]. A comparison of cleared (gorse plants cut and removed) and uncleared (control) plots in New Zealand found that the number of seeds germinating under a dense thicket of gorse (control) was about

130 seeds/m²/year and remained relatively constant over time. Conversely, germination proceeded rapidly on the cleared plots and the number of germinating seeds was about 520/m² in 16 months, after which germination rates slowed as the plots became covered with grass [39]. The main flush of germination in gorse usually occurs in late spring once soil temperatures reach about 61 °F (16 °C) [40,98]. The flush of germination in fall is much smaller, unless preceded by a late-summer fire after which germination will exceed spring levels. Further germination occurs in spring after a fall fire and it is only in the second spring after a fire that seedling growth becomes negligible under "open ground" conditions [98]. Only 25% of the total seeds in the top 4 inches (10 cm) of soil germinated during 3 growing seasons after clearing, leaving a large seed reserve below 2 inches (5 cm) capable of germinating after soil disturbance at a later date [40].

The reason for the postclearing flush of gorse germination is unclear. The most obvious change in the seedbed is in light intensity; however, Ivens [41] found no light requirement for gorse germination. Soil disturbance during clearing may expose previously buried seed and thus stimulate germination. Gorse seeds buried below 2 inches (5 cm) cannot germinate successfully unless brought to the soil surface by disturbance (R.L. Hill and A. H. Gourlay unpublished data cited by [34]). Clearing vegetation also exposes seed to greater temperature fluctuations and moisture availability, which might stimulate germination of gorse seed [39,41].

Gorse seed germinates best at temperatures of 59 to 66 °F (15-19 °C), agreeing with field observations of germination peaks in late spring and early summer [40]. Germination occurred at a minimum temperature of 32 °F (0 °C) supporting observations of seedling emergence during winter [39]. Temperatures above 79 °F (26 °C) inhibited germination, and above 95 °F (35 °C) viability was lost. Germination was not stimulated by a wide range of alternating temperature regimes, suggesting that exposure to fluctuating temperatures after vegetation clearing does not adequately explain observed increases in germination rates [41].

Ivens [41] suggests that decreased gorse germination under a gorse canopy may be due to interception of rain by the canopy. Rainfall of 0.07 inch (1.8 mm) was completely absorbed by a gorse canopy in New Zealand, and only 20% to 30% of rainfall exceeding 0.5 inch (12 mm) reached the ground (Aldridge 1968, as cited by [41]). Similarly, throughfall measured in mature gorse shrubland in Spain was about 35% to 50% of gross rainfall, and increased by 50% during the first 2 years after fire [82]. Clearing of thicket would therefore be expected to result in considerably increased soil moisture levels and, although no information is available on the moisture requirements of gorse seed, this might well be a major factor in germination [41]. On experimental plots cleared by hand and kept free of vegetation by hand-weeding, gorse germination coincided with soil temperatures around 64 °F (18 °C) and high soil moisture levels [40].

Seedling establishment/growth: Following germination in the field, seedling survival is largely dependent on type and abundance of associated species. Under a gorse canopy seedling mortality rates were 70%, compared to 41% seedling mortality after hand-clearing of gorse [39]. Gorse seedlings also do not often establish in the presence of strong vigorous pastures ([70] and references therein). On experimental plots cleared by hand and kept free of other vegetation by hand-weeding, gorse seedling establishment continued over time. On comparison plots that were not weeded, several grasses and forbs established along with gorse, and gorse seedling densities were much lower than on weeded plots (97 gorse seedlings/m² with competition, compared to 435 gorse seedlings/m² without, 1 year after initial clearing) [40].

At another site plots were cleared by root-raking or burning after spraying gorse, and then planted with a pasture mix and grazed. Large numbers of gorse seedlings established in the 1st few weeks after clearing, when there was little competing vegetation, and seedling numbers declined rapidly thereafter (by 90-95%

in 20 months) as the ground cover of surviving gorse seedlings and sown pasture species increased [40]:

		2,4,5-T, burned, planted		2,4,5-T/picloram, burned, planted	
		gorse/m²	% cover	gorse/m²	% cover
June	1978	618	2	371	5
October	1978	309	54	177	73
January	1979	120	70	108	84
March	1979	141	77	123	84
June	1979	46	74	69	71
October	1979	23	83	50	75
January	1980	29	99	44	92

Where plots were cleared by root-raking and not grazed, fewer gorse seedlings died and growth was more vigorous. Where original gorse cover was sprayed but not removed, very few gorse seedlings established in the first 6 months but as the canopy decomposed and opened, both volunteer grasses (mainly common velvetgrass (*Holcus lanatus*)) and gorse established, although gorse seedlings were weak at first. At the end of the study there were more gorse seedlings on this plot than any other plot [40]:

		rootraked, planted, not grazed in first season			2,4,5-T/picloram, not burnt, not planted, not grazed	
		gorse/m²	% cover		gorse/m²	% cover
June	1978	728	2		8	0
October	1978	466	54		14	6
January	1979	476	83		273	22
June	1979	272	100		193	62
January	1980	168	100		309	79

This study did not specify what type of grazing animals were used, but it is implied that grazing pressure on gorse seedlings, along with competition for resources from pasture species, increased gorse seedling mortality [40]. Both defoliation and shading reduce dry matter production in gorse seedlings; however, seedlings generally survived such treatments in laboratory experiments. It was only when defoliation was below the growing point, especially in seedlings that had developed beyond the cotyledonary stage, that seedling death always occurred [73].

Four separate growth stages of gorse, with distinct forms and foliar characteristics, have been distinguished as cotyledon, juvenile, juvenile/mature, and mature [98]. The transformation from juvenile to mature involves a change in leaf shape, modification in the activity of branch meristems, and acceleration of extension and growth. Juveniles typically have 3-foliate leaves. As rapid extension and growth occurs, spines begin to develop in leaf axils, followed by loss of leaves and branching of spines as plants mature. The distinction between growth phases is not always sharp [53]. During development the quantity and composition of the foliar wax changes, the cuticle thickens, the root:shoot ratio changes and, consequently, herbicidal effectiveness decreases [98].

Gorse plants grow quickly. According to a review by Hoshovsky [37] 1 year-old stands are capable of producing about 1,100 lbs of dry matter/acre/year, with older stands producing 3,300 lbs/acre/year. Stem diameters increased at an annual rate of 5 mm and height increased by 8 inches (20 cm) in a New Zealand study. Plants achieved maximum heights of 23 feet (7 m) and maximum stem diameters of 8.5 inches (21.7 cm). At maturity, 15 years after establishment, there were 60,000 gorse stems/ha and a basal area of 51 m^2/ha. Growth rates of both height and stem diameter gradually declined with age (Lee and others1986, as cited by [70]). After a mid-summer wildfire on a southern New Zealand peatland, gorse sprouted from the lower portions of old stems within 4 months of burning. Height growth was more rapid on sprouts than on seedlings. Gorse seed germinated in the following spring after fire and seedlings reached 1.2 inches (3 cm) tall (maximum) 10 months after fire, while sprouts were 12 inches (30 cm) tall at that time. At 15 months, seedlings of erect, unbranched form were up to 26 inches (65 cm) tall. Height of gorse sprouts increased gradually between 39 months (51 inches (130 cm)) and 120 months (83 inches (210 cm)) [42]. Initial growth of gorse is slow in Oregon. After the 2nd or 3rd year following germination, growth accelerates both vertically and laterally. The plant may reach the height of 6 feet (2 m) within a period of 8 to 10 years [32]. Growth of vegetation in mature gorse shrubland is negligible ([82], and references therein).

Asexual regeneration: Information in the literature is conflicting regarding the ability of gorse to sprout from the roots. A review by Clements and others [12] suggests that vegetative reproduction by gorse may occur via creeping roots, and that root systems or root fragments are capable of producing plants that will flower within 6 months. However, the literature that they cite for this information does not support these conjectures. This review also suggests that both roots and shoots are capable of sprouting, but that gorse does not form adventitious buds below the 1st root branch (Hebda personal communication, as cited by [12]). Conversely, research cited by Prasad [64] suggests that gorse does not appear to regenerate from the roots in either field or greenhouse conditions (Prasad and Robinson 2002, as cited by [64]).

There is general agreement in the literature that gorse sprouts from stem tissue following damage to aboveground plant parts by mechanical means (e.g. cutting or bulldozing) [12,32,64] or by fire [5,42,74,80,82] (see Plant Response to Fire). Cutting gorse in British Columbia resulted in prolific sprouting on the stem from anywhere slightly below the root crown and upwards. Sprouting can occur on the stump as early as 3 weeks after cutting [64]. Other observations in British Columbia indicate that about 90% of gorse plants sprout from stumps after cutting (Robinson personal communication, as cited by [12]).

Finally, a review by Richardson and Hill ([70] citing Chater 1931) suggests that gorse does not reproduce vegetatively, although procumbent branches may send out adventitious roots.

SITE CHARACTERISTICS:

General: Gorse establishes in northeastern [28,77] and western [15,32,57,63] coastal areas in the U.S. Gorse is most common in open or disturbed places, especially roads, abandoned or overgrazed pastures, old agricultural fields, sand dunes, gravel bars, fence rows, logged areas, and postfire communities [15,33,37,44,45,63]. Gorse and brooms also invade forest understories and adjacent openings, and coastal grasslands in Sierra Nevada and coast ranges ([2,67] and references therein). In describing sites that should be monitored as susceptible to gorse invasion, King and others [45] include ravines and riparian areas where running water carries gorse seeds [45]. The spread of gorse in parts of its Canadian range has been linked to agriculture, where gorse has been planted as hedgerows and subsequently invaded pastures and roadsides (Ussery personal communication, cited by [12]).

In New Zealand gorse commonly invades riverbeds and riparian areas [5,94], steep hillsides [5,24], and the understory of planted Monterey pine (*Pinus radiata*) [24]. Observations suggest that infestations often begin on riverbeds and spread from there [5]. Where dense stands of gorse and Scotch broom occur along rivers in New Zealand, Scotch broom dominates near the water's edge and gorse cover increases with distance from the edge [94]. Gorse is capable of invading peatlands and wetlands, with or without fire; however, fire appears to encourage expansion of established gorse clumps in these areas [42].

Climate: Gorse occurs in temperate lowland regions and coastal areas. It does not occur in arid climates or in continental regions where there are extremes of heat and cold [15,97]. Mature gorse plants can withstand, but do not thrive, in areas with severe frosts, and seem to prefer habitats sheltered from cold winds [97]. Gorse growing in England suffered severe frost damage during a winter when temperatures fell to -5.4 °F (-20.8 °C). However, the plants recovered completely within 2 years ([70] and references therein). Expansion of its range to cooler areas at higher altitudes and latitudes British Columbia or the Atlantic Coast may be hindered by severe winters; however, the presence of gorse in the Queen Charlotte Islands, Canada, and in parts of Scandinavia indicates its potential for northward expansion in coastal areas ([12] and references therein). Gorse grows optimally in areas where average monthly temperatures are above freezing and prefers areas where the mean daily minimum temperature of the coldest month is above 36 °F (2 °C). The mean temperature of the warmest month where gorse occurs in Europe is 64 to 68 °F (18-20 °C) [70]. Gorse seed germination is limited by temperature extremes [41]. Day length may be a factor in latitudinal distribution; short days (<8 hrs) inhibit plant maturation and prevent thorn formation and flowering [97].

Gorse occurs in coastal areas that remain cool and moist most of the year [45], and where rainfall is evenly distributed throughout the year in the range of 26 to 35 inches (650-900 mm) [70]. It also occurs in some areas with relatively dry summers [70]. The relatively low leaf surface area and tap root enable gorse to withstand seasonal periods of reduced precipitation (Zielke and others 1992, as cited by [12]).

Soil: Literature reviews indicate that gorse occurs on most soil types, but only rarely on highly calcareous soils [37,70,97]. Growth was more prolific on soils containing less calcium than the other soils evaluated, and gorse seed germination and seedling growth are reduced on highly calcareous soils ([70], and references therein). It frequently occurs on sandy soils [2,57,63], and has been recorded growing on serpentine soils [37]. Gorse is often a pioneering species in disturbed areas of low fertility [32,37,70,72]. Gorse is tolerant of relatively low pH in the range of 3.5 to 4.5 [55]. It can thrive in well-drained soils and in areas with a high water table [37], but cannot tolerate waterlogged conditions [97].

Elevation: Gorse is found mainly at low elevations in coastal areas [12,33,63]. It occurs from sea level up to 1,300 feet (400 m) in California [33], and up to 4,600 feet (1,400 m) in parts of New Zealand [97].

SUCCESSIONAL STATUS:
Early successional: Gorse is often a pioneering species in areas where vegetation is disturbed by fire or other events that open the canopy such as logging or mining [21,34,42,70,72,97]. Nitrogen fixation in gorse facilitates its establishment and persistence in early-successional, disturbed environments, and nitrogen and organic matter accumulate on invaded sites as they age [72].

Once several reproducing gorse individuals are established, a stand may exclude establishment of native vegetation and perpetuate itself for many years [12,32,38,64]. The evergreen status and canopy architecture of gorse limit light available to understory species. On some sites in California, invasion of gorse and other nonnative shrubs may convert grassland to shrubland, indefinitely (see Fire Ecology) [44]. Very little establishment of native woody species occurred under gorse within 25 years of its establishment on sites in New Zealand (Lee and others1986, as cited by [12,70]). In Great Britain only a few woody species grew under a canopy of gorse (Grubb and others1969, as cited by [12]).

Gorse dominance may be maintained in some areas by repeated burning [22,96,97]. Gorse structure and chemical composition fuel fire spread (see Fire Ecology and Fire hazard potential), and regeneration by sprouting and seedling establishment tends to be prolific after fire. Burnt gorse stumps coppice readily, and shoots grow rapidly (see Fire Effects). With periodic burning, gorse communities are maintained at an early-successional or fire-climax stage. Gorse is described as one of 2 fire climax species in forests in Great Britain, along with a common associate, heather [51].

In fire-maintained heathlands in France, where gorse is a dominant component, postfire succession varies depending on fire frequency and severity and prefire plant community composition. After low severity fires establishment is mostly from sprouting, is more rapid, and results in the same floristic composition as prefire communities. Gorse shared dominance with heath (*Erica* spp.) after low-severity fire in dry heath, and with bracken after low-severity fire in tall heath. Recolonization after high-severity fire occurs exclusively from seeds, which requires more time than after a low-severity fire, and postfire vegetation differs from that which occurred before the fire. After high-severity fire in dry heath, gorse was the 1st plant to germinate, and 1 year after establishing its relative frequency was 10%. Common velvetgrass established shortly thereafter, and developed 30% to 40% coverage 1 to 3 years after fire, completely altering heathland appearance. Gorse frequency increased more rapidly between 1 and 2 years after fire, and 5 years after fire it accounted for 75% to 85% of plant cover, while heather accounted for 10% to 25% cover. After high-severity fire in tall heath, gorse, shrubby blackberry, and common velvetgrass were among the first plants to establish. Gorse maintained a low relative frequency for 2 years after fire, while shrubby blackberry and common velvetgrass increased. Two to 3 years after fire gorse gradually began to dominate shrubby blackberry; and around 4 years after fire gorse began to dominate common velvetgrass [75].

The maximum age recorded for gorse individuals is between 29 and 46 years; and at about 15 years gorse plants may become top heavy and fall over, creating gaps that may allow other species to establish ([12,70], and references therein). When native tree species establish under gorse, they may overtop gorse and eventually shade it out if fire and grazing are excluded [17,38,95,96,97].

On a New Zealand site, a gorse-dominated community senesced and collapsed at 30 years, and the authors predicted that the establishment of native canopy and subsequent demise of gorse would take about 50 to 60 years (Lee and others1986, as cited by [70]). Similarly, Wilson [96] predicted that nonnative shrubland communities dominated by gorse and Scotch broom would revert to native forest in about 50 years if fire and grazing were excluded on a forest reserve in New Zealand. Gorse has replaced native broom teatrea (*Leptospermum scoparium*) and burgan (*Kunzea ericoides*) as the major early successional shrub over much of the New Zealand lowlands, especially following fire and pasture abandonment [21,95]. Before European settlement, burgan and broom teatrea dominated the early phases of vegetation succession, giving way to taller broad-leaved species after about 100 years or more. In contrast, the process takes only about 30 years through gorse ([95] and references therein). On one site, for example, postfire vegetation was dominated by gorse for 10 years. In stands between 16 and 33 years old, gorse and broom teatrea shared dominance, and older stands were dominated by kamahi (*Weinmannia racemosa*) [21].

Gorse longevity depends on site conditions and associated species. For example, gorse is a primary colonizer after mining in Great Britain, and occurred on the oldest study site, 116 years after mining ceased [72]. Gorse does not form a dense canopy in lowland heath in England. It has a shorter life span than heather, degenerating and breaking apart after about 15 years [55].

According to several literature reviews, gorse seedling establishment is inhibited by dense vegetation, and gorse generally exhibits low shade tolerance. Under low light conditions plants produce sparse foliage and few flowers. Gorse survival is greatest in high light areas ([12,20,37,97] and references therein).

In a laboratory experiment, however, gorse was tentatively classified as shade tolerant, although further tests are needed for this to be definitive. Gorse seedlings had greatest survival (~99%) in both moderate shade (30% full sunlight) and in 100% full sunlight, and 74% survival in deep shade (3% full sunlight). Rates of net photosynthesis were somewhat, although not significantly ($P<0.005$) higher in moderate shade versus full sun, and dark respiration was significantly higher in full sun than in moderate shade. The authors speculate that because gorse tends to form a dense canopy with large biomass accumulations, seedlings are likely to experience deep shade when recruiting under the canopy of adult gorse shrubs [91].

In another laboratory study the effects of shading with and without defoliation were examined, and it was found that shading with and without defoliation reduced growth and delayed spine formation but did not kill seedlings. Effects of shading for 8 weeks on gorse seedlings were as follows [73]:

	Shoot dry weight (mg)	Height (cm)	Width (cm)	Number of shoots	Spine development
Full light	571	16.5	3.7	4.2	2.7
80% light	436	17.5	3.1	1.8	2.3
40% light	309	18.5	2.9	1.6	1.7
20% light	183	17.2	2.6	1.2	1.2

Gorse seedlings responded to defoliation by becoming prostrate, only those defoliated well below the growing point died, and some sprouted from callus tissue after defoliation. Effects of shading on gorse seedlings for 8 weeks after defoliation were as follows [73]:

	Shoot dry weight (mg)	Number of shoots	Spine development
Full light	1075	7.40	2.35
80% light	650	7.04	2.00
40% light	252	3.63	1.50
20% light	275	4.40	1.04

SEASONAL DEVELOPMENT:
Germination of gorse seeds may take place at any time of the year, but peak seedling emergence occurs from spring to mid-summer, and again in fall [12,40,70].

Flowering in gorse is highly variable and rarely uniform in any one area. Information is scarce as to whether this is due to random flowering by individual plants, or multiple flowering on the same plants [97]. The main flowering period is normally spring and early summer, but a 2nd flowering period occurs in fall [15,70,97]. It is common for some flowers to be present throughout the year [97].

Flowering dates by location are reported as follows:

Location	Flowering dates
California	February to July [57], March to May [37]
northeastern U.S.	June [28,77]
West Virginia	May to September [84]
Vancouver Island, British Columbia	peak in May to June, sometimes in September [70]

FIRE ECOLOGY

SPECIES: Ulex europaeus

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations: Gorse is referred to as a "pyrophytic" (fire-loving) species in its native range [25,65].Gorse responds to fire by sprouting from the basal stem region (coppicing) and by establishing from soil-stored seed [5,42,74,92,98,99]. Postfire regeneration of gorse can be prolific and rapid [42,80,82].

While most gorse plants typically survive fire, severe ground fire that consumes most or all of a deep organic surface horizon typically kills gorse plants [29,75,93]. Fire typically accelerates germination of gorse seeds [99], depending on depth of burial and fire severity. Because lethal temperatures rarely penetrate below 1 cm, loss of gorse seed from the soil seed bank is due mainly to germination and not mortality [74]. An exception may be high-severity ground fires where seed is contained in the surface organic horizons and is consumed by the fire [93] (see Fire Effects).

Flammability/fuel characteristics: It is reported in the literature that gorse has a high concentration of volatile oils in its foliage and branches [15,64] and produces considerable biomass with abundant dead material in the plant's center [45,64]. It is also commonly reported that gorse stands are highly flammable [15,45,64], burn rapidly and with high intensity [12,38,45], and pose a serious fire hazard [32,36,64]. Relatively little research is available, however, that examines gorse fuel characteristics (see Fire hazard potential).

Fire regimes: In its native range on the western seaboard of continental Europe and the British Isles, gorse often occurs as a dominant species in various heathland plant communities (see Habitat Types and Plant Communities). Fire in these heathlands is recurrent [25,34,80], and fire frequency dependent on fire severity. Frequent, low-severity fires maintain the fire-climax, often dominated by gorse and other woody shrubs. High-severity fire may result in establishment and dominance of nonheathland species and reduced fire frequency [25,29,75]. Gorse is described as one of 2 fire climax species in forests in Great Britain [51].

No published research is available that addresses the potential for gorse invasions to alter fire regimes in invaded communities in North America. Gorse is invasive in sandy coastal areas, coastal scrub, and grasslands in California, Oregon and Washington; and is also associated with the Oregon white oak ecosystem in western Washington and British Columbia [12,46,64]. Gorse also occurs in early succession after fire or logging in Douglas-fir forests in the northwestern U.S. [38]. No additional information is available on invaded communities on the west coast, and no information is available for invaded habitats on the east coast of North America.

It is unclear how the presence of gorse affects fire regimes in invaded communities. In general, in ecosystems where gorse replaces plants similar to itself (in terms of fuel characteristics), it may alter fire intensity or slightly modify an existing fire regime. However, if gorse is qualitatively unique to the invaded ecosystem, it has the potential to completely alter the fire regime (sensu [6,18]). In Australia, observations indicate that high fire danger occurs in areas where nonnative shrubs such as gorse form dense, tall, flammable undergrowth below sclerophyll forests. In this case, nonnative shrubs pose a greater fire hazard than native shrub communities. When this nonnative shrub layer burns it typically ignites the sclerophyll tree canopy, whereas native species (which are shorter and less dense) typically would not. Additionally, it takes over 10 years after fire in native vegetation for a relatively dense climax scrub stratum to establish, and only 2 years for nonnative species [13]. Gorse invasions may pose similar threats in invaded Oregon white oak and Douglas-fir communities in the U.S. A similar species, Scotch broom, is invasive in similar habitats, and research indicates changes in fuel characteristics and fire behavior in invaded Oregon white oak communities [10,88].

Herbaceous communities dominated by nonnative annual grasses and forbs of Mediterranean origin occur throughout the Coast Ranges and foothills of the Sierra Nevada and Cascade ranges. These communities were largely created by anthropogenic burning, were further maintained by intensive land use with fire and livestock grazing, and have long dominated some landscapes that would naturally support woody vegetation. In recent decades, however, grazing has been eliminated and anthropogenic fires reduced such that woody vegetation is reestablishing. Along with native shrubs, nonnative shrubs such as gorse, Scotch broom, and French broom colonize these sites. Nonnative shrub colonization of grasslands may decrease fire frequency but increase fuel loads and alter fire behavior ([44] and references therein).

The following table provides fire return intervals for plant communities and ecosystems where gorse is important. For further information, see the FEIS review of the dominant species listed below. This list may not be inclusive for all plant communities in which gorse occurs. For information on plant communities or ecosystems that are not listed below, see the complete FEIS Fire Regime Table.

Community or ecosystem	Dominant species	Fire return interval range (years)
California chaparral	*Adenostoma* and/or *Arctostaphylos* spp.	<35 to <100
coastal sagebrush	*Artemisia californica*	<35 to <100
California montane chaparral	*Ceanothus* and/or *Arctostaphylos* spp.	50-100 [61]
California steppe	*Festuca-Danthonia* spp.	<35 [61,85]

Jeffrey pine	*Pinus jeffreyi*	5-30
Pacific ponderosa pine*	*Pinus ponderosa* var. *ponderosa*	1-47 [1]
coastal Douglas-fir*	*Pseudotsuga menziesii* var. *menziesii*	40-240 [1,56,71]
California mixed evergreen	*Pseudotsuga menziesii* var. *menziesii-Lithocarpus densiflorus-Arbutus menziesii*	<35
California oakwoods	*Quercus* spp.	<35 [1]
coast live oak	*Quercus agrifolia*	2-75 [30]
canyon live oak	*Quercus chrysolepis*	<35 to 200
blue oak-foothills pine	*Quercus douglasii-P. sabiniana*	<35
Oregon white oak	*Quercus garryana*	<35 [1]
California black oak	*Quercus kelloggii*	5-30 [61]
western redcedar-western hemlock	*Thuja plicata-Tsuga heterophylla*	>200 [1]

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

POSTFIRE REGENERATION STRATEGY [83]:
Tall shrub, adventitious bud/root crown
Ground residual colonizer (on-site, initial community)
Initial off-site colonizer (off-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: Ulex europaeus

- 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:
Aboveground gorse biomass may be consumed by fire, depending on fire behavior. Fire-killed stems may remain upright for several months [42], and some stems may survive [98]. Most gorse plants survive fire, and postfire sprouting from the basal stem region (coppicing) is common (see Plant Response to Fire) [74].

Gorse seeds are either killed, scarified, or unaffected by fire [98,99], depending on depth of burial and fire severity.

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
Severe, ground fires that consume most or all of a deep organic surface horizon typically kill gorse plants [29,75,93] (see Discussion and Qualification of Plant Response).

Burning may accelerate germination of gorse seeds, and in some instances can kill or consume gorse seed [99]. For example, Miller (1992, as cited by [12]) reported that fire at an Oregon site reduced the number of viable gorse seeds in the soil by 54% (from 2,883 to 1,318 seeds/m²). Because lethal temperatures rarely penetrate the soil below 1 cm, loss of gorse seed from the soil seed bank is due mainly to germination and not mortality [74]. An exception may be high-severity ground fires where seed is contained in the surface organic horizons and is consumed by the fire. This might explain the absence of gorse regeneration after a ground fire in a heathland in northern Spain [93] (see Plant Response to Fire).

PLANT RESPONSE TO FIRE:
Gorse responds to fire by sprouting from the basal stem region and by establishing from seed in the soil seed bank [5,42,74,92,98,99]. Postfire regeneration of gorse can be prolific and rapid [42,80,82].

Immediately following experimental burns in an area of gorse scrub in northwest Spain, gorse stem phytomass was reduced by approximately 318 g/m² over prefire levels. An increase in aboveground gorse biomass of 245.5 g/m² and 1366.6 g/m² were recorded in the 1st and 2nd postfire years, respectively [80]. The percentage of ground covered by gorse quickly and steadily increased after these fires [82]:

	Before fire	Months after fire							
		3	7	10	13	20	26	33	37
Gorse cover (%)	94.87	5.31	14.41	38.83	43.75	49.86	57.90	67.89	71.49

The rapid regeneration of gorse was primarily from new shoots on old root systems. After 3 years, the main difference in cover between the control plots and burned plots was that there was greater overlayering of vegetation on the control plot [82].

Johnson [42] suggests that sprouting is more important than seedling establishment for postfire regeneration of gorse. After a mid-summer wildfire on a southern New Zealand peatland, gorse sprouted from lower portions of old stems within 4 months of burning, and seed germinated the following spring. Height growth was more rapid on sprouts than on seedlings. Gorse seedlings reached 1.2 inches (3 cm) tall (maximum) 10 months after fire, while sprouts reached 12 inches (30 cm) tall at that time. Fifteen months after fire, sprouts were 35 inches (90 cm) and seedlings 26 inches (65 cm) tall. Cover of gorse on these sites averaged about 2.5% four months after fire, 5% ten months after fire, and 15% fifteen months after fire. Twenty-two to 28 months after fire, gorse cover was about 35%; and 39 to 120 months after fire gorse cover was 70% to 85% [42].

Gorse seed in the soil seed bank germinates slowly, over a long period, in undisturbed sites dominated by gorse [39] (see Germination). Observational and experimental evidence from New Zealand indicates that clearing vegetation from gorse-dominated stands results in a flush of germination of gorse both with [73,74] and without fire [39]. Postclearing flush of gorse germination may be due to changes in light intensity or greater temperature fluctuations at the soil surface, but this remains unclear. For example, observations suggest that light is not essential for gorse seed to germinate (Zabkiewicz personal communication cited by [39]).

Reviews suggest that changes in soil temperatures during fire may scarify gorse seed or volatilize organic compounds in the seed environment that had inhibited germination and, when extreme, may kill gorse seed [74,97]. Laboratory tests indicate that germination of gorse is poor without pretreatment (e.g., soaking in boiling water for 30 seconds or cutting the seed coat), and may be enhanced by exposure to heat. Dry heat of 220 °F (105 °C) for 5 minutes resulted in at least 79% of gorse seeds germinating (Butler 1976, as cited by [74]). After exposure to wet or dry heat of 212 °F (100 °C) for 5 minutes or less or to 180 °F (80 °C) or 140 °F (60 °C) for any duration germination rates were similar to mechanically scarified seed. Reduced germination or increased time to complete germination occurred when seeds were exposed to 212 °F (100 °C) for 5 minutes or more. Virtually total seed sterilization could be attained by exposure to 300 °F (150 °C) for 1 minute. Wet heat became lethal to gorse seed at lower temperatures or shorter exposures than the equivalent dry heat treatment [99].

Temperatures recorded in the field during fire in gorse stands range between 390 °F (200 °C) and 1,100 °F (600 °C) in the surface litter 0.2 inch (0.5 cm), and decline markedly with increasing depth. Maximum temperatures in the litter (top 0.2 inch (0.5 cm)) during a burn of felled gorse and broom teatrea in New Zealand were 390 °F (200 °C), 480 °F (250 °C), and 1,100 °F (600 °C) at lightly, moderately, and heavily burned sites, respectively. At the heavily-burned site, where most of the surface litter was destroyed, temperatures of 410 °F (210 °C) and 280 °F (140 °C) were recorded in the litter at 1 and 2 inch (2.5 and 5.0 cm) depths, respectively. During another fire in gorse, temperatures above the surface reached 570 °F (300 °C) to 1,500 °F (800 °C), while soil temperatures were less than 212 °F (100 °C) ([74], and references therein). Rolston and Talbot [74] report soil temperature changes over time (in the zone where gorse seeds occur) during burning of gorse. Lower overall plant and soil moisture levels appear to be associated with higher soil temperatures during the burn. On the 2 sites where high temperatures were recorded, temperatures 1 to 2 mm below the soil surface exceeded 220 °F (105 °C) for 153 and 156 seconds, respectively, and exceeded 300 °F (150 °C) for 102 seconds on both plots. Even though high temperatures were recorded above the surface and at 1 to 2 mm below the surface, only small changes in temperature were recorded at greater depths. These observations suggest that soil temperatures are unlikely to become lethal to gorse seed at depths greater than 0.4 inch (10 mm) [74]. Temperatures recorded at 2 inches (5 cm) depth during fire in gorse-dominated shrubland in Spain were less than 120 °F (50 °C) in all plots (Diaz Fierros and others 1990, as cited by [82]).

Most gorse seed occurs within the top 0.8 to 2.4 inches (2-6 cm) of soil, although density and distribution of gorse seed in the soil is highly variable, both within and between sites [39,74,99]. Some research indicates greater than 60% reduction of gorse seed in the top 4 inches (10 cm) of soil after fire [74,99] (see Seed banking). In a dense, 13- to 16-foot (4-5 m) tall gorse thicket in New Zealand, Ivens [39] measured 10,000 gorse seeds/m² in the top 6 inches (15 cm) of soil, about half of which occurred in the litter or top inch (2.5 cm). Among soil samples collected from several sites dominated by gorse among 5 districts in New Zealand, most (90% on average) gorse seed occurred in the top 2.4 inches (6 cm) of soil, both before and after burning. Density of gorse seed was reduced about 66% on average after fire. Burning did not affect viability of gorse seed remaining after fire, and most gorse seed (>80%) in the top 35 inches (30 cm) of soil was viable before and after burning [99]. Rolston and Talbot [74] measured 2,660 gorse seeds/m² in the top 4 inches (10 cm) of soil, with 71% of the seed in the top inch (2.5 cm) before spraying and burning. Five weeks after burning gorse seed density had declined by 62% to 1,000 seeds/m² in the top 4 inches (10 cm) and by 59% in the top inch (2.5 cm). The authors suggest that most of the decline in seed numbers can be attributed to germination of buried seed after fire. Germination rates of buried gorse seed before and after burning were 73% and 79%, respectively. There appears to be no relationship between soil temperatures achieved during the fire and the germination capacity of remaining gorse seeds. Even where temperatures immediately below the soil surface exceeded 300 °F (150 °C) for 102 seconds there was no reduction in germination capacity [74]. Most of the gorse growth after combined herbicide and burning treatments is from seedling establishment and not from sprouting (Zabkiewicz and Gaskin unpublished, as cited by [99]).

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Much of the information on the response of gorse to fire comes from studies of wild and prescribed fire in its native range in Spain and France, and from studies conducted in New Zealand in association with silvicultural objectives. The degree of sprouting and seedling establishment and the relative importance of these regeneration strategies for gorse in the postfire environment may depend on fire season and severity, fire frequency, associated vegetation, and interactions with other management practices.

Severity: In its native range in western Europe, gorse occurs on heathlands where both wild and prescribed fires commonly occur [25,29]. Postfire succession on these sites depends on a number of factors including the season in which fire occurs, which in turn affects fire severity.

A literature review and postfire observations by Gloaguen [29] indicate that season and severity of fire have important consequences for postfire recolonization in heathlands in France. After "minor" (low-severity) fire, original heathland species usually establish; and after high-severity fire another vegetation type may replace the original heathland. The author describes succession after a mid-summer (1976), high-severity fire in tall heathland where gorse dominated the prefire community. After fire only a few stumps of gorse and dwarf gorse, and a few tufts of bristle bent survived, and postfire colonization was mainly from species foreign to the original heathland. Vegetation began to develop in February 1977. Thirteen years after fire the original gorse tall heathland had been replaced mostly by birch wood (*Betula pendula* and *B. pubescens*), with rare and scattered occurrence of gorse, within patches of dwarf gorse [29].

Gorse responded differently to low- and high-severity fires in dry and tall heathland communities in France, with greater severity effects in tall-heath than in dry heath. At 2 neighboring littoral heathland sites (made up of dry heath, mesophyllic heath, and tall heath types) on identical soils on the coast of France, 2 fires of different severity occurred within 6 months in fall 1985 and spring 1986. The fire at site 1 was a low-severity "flash-fire" (occurring in spring), while that at site 2 was a high-severity "humus-fire" (occurring in fall). Aboveground biomass was completely consumed by both fires, and after the high-severity fire the soil surface remained completely bare for 7 months. Gorse had 40% to 75% cover in dry heath, and 95% cover in tall heath before fire. Gorse did not occur in mesophyllic heath. Establishment of plant cover after low-severity fire was from stump sprouting, and began less than 2 months after fire on all heathland types. After low-severity fire in dry heath, gorse grew rapidly and maintained the same frequency for 5 years after fire. After low-severity fire in tall heath, gorse developed from shoots on incompletely burned stumps. Establishment of plant cover was exclusively from seeds after high-severity fire, and required more time than after low-severity fire. After high-severity fire in dry heath, gorse was the first plant to germinate (presumably from the soil seed bank), and 1 year after establishment its relative frequency was 10%. Gorse frequency increased more rapidly 1 to 2 years after fire, and 5 years after fire it accounted for 75% to 85% of plant cover. After high-severity fire in tall heath, gorse was among the first plants to establish. Gorse maintained a low relative frequency for 2 years after fire, and gradually increased thereafter, dominating the plant community after about 5 years [75] (also see Successional Status).

Another study in dry and tall heathland in France found differences in postfire succession following fires in different seasons and of different severities. After a summer fire on dry heathland sites, vegetation establishment was slow, and soil remained mostly bare for nearly a year. Two and a half years after fire gorse had 20.3% cover, which was about one-third its preburn cover (70%). After summer fire in tall heathland dominated by gorse, gorse was present in the 1st postfire year, when herbaceous species dominated, and was among the dominant species (along with Scotch heath (*Erica cinerea*)) 3 years after fire. After a spring fire on the same site 7 years later, vegetation developed much faster and gorse rapidly established tall cover (>90% at 3 years). Following a high-severity fire in tall heath, bryophytes and herbaceous species dominated for the first 6 years, after which chaemaephytic species including gorse, became dominant. Gorse abundance continued to increase through the 7th postfire year. A comparison of gorse development after fires of different severities in different seasons shows that gorse cover reached 50% one year after a low-severity spring fire, 2.5 years after a low-severity summer fire, and 10 years after a high-severity summer fire. The author gives no indication whether gorse regeneration was primarily from sprouts, seedlings or both [25].

Studies of heathland in Spain indicate that postfire succession depends on fire severity and prefire vegetation. Regeneration of gorse after fire was both by sprouting and from seed after a low-severity fire in gorse-dominated heathland in northern Spain in February 1990. In May 1990, 3 months after fire, gorse density was very high, and between May and September, about two-thirds of these plants died. The number of gorse plants remained about the same thereafter and reached a maximum height of 3 inches (7 cm) during the 2 years of study [92]. In another heathland in northern Spain dominated by gorse, postfire regeneration was studied for 3 years after a mixed-severity fire. In the areas of severe burn (organic horizons burned for several days and reduced by 2 to 4 inches (5-10 cm)) there was no regeneration of woody plants. Gorse reproduced by sprouts and seedlings and showed the highest regeneration ability among species present in both the low-severity burn areas (organic matter reduced < 1.2 inches (3 cm)) and moderately burned areas (duff reduction between 1.2-2 inches (3-5 cm)). Cover of gorse in low-severity burn areas 2, 3, and 4 years after fire was 9.7%, 12.2%, and 14.6%; and gorse cover in the moderately burned areas was 8.0%, 17.7%, and 37.7%, respectively, compared to 25.8% cover in unburned control areas [93].

Frequency: Observations from New Zealand suggest that dominance of gorse is maintained by frequent burning. On hills formerly dominated by hard beech (*Nothofagus truncata*) and repeatedly burned, gorse often dominates the fire-seral communities. Furthermore, it is suggested that native forest can only be invaded by gorse when disturbed [21]. It is also suggested that gorse that has been repeatedly burned is difficult to remove, as it develops a dense network of roots with repeated burning [5].

Other management: Forest managers in New Zealand use "burn-off" operations, in conjunction with chemical sprays, for clearing scrub (often dominated by gorse) as site preparation for planting trees. It has been found that most gorse growth after such a treatment is from seedling establishment and not from stem sprouting (Zabkiewicz and Gaskin unpublished, as cited by [99]), likely due to inhibition of sprouting by the herbicide treatment. Conversely, Johnson [42] suggests that sprouting is more important after wildfire in New Zealand peatland.

FIRE MANAGEMENT CONSIDERATIONS:
Fire as a control agent: Fire alone will not likely control gorse populations, as it typically results in regeneration of gorse by sprouting and by seedling establishment (see Plant Response to Fire). Additionally, a review and simulation model presented by Rees and Hill [69] suggests that it takes several years for gorse stands to develop enough litter and dry stems to allow a fire to burn; and a single fire can allow the establishment of a stand that can persist for 30 years and develop a substantial seed bank that could persist for even longer (see Seed banking). However, burning has been used to manage gorse in many areas for decades. A review by King and others [45] suggests that, if correctly timed, burning will reduce gorse biomass, reduce the soil seed bank, destroy seeds still on the plants, kill seedlings, and reduce the number of years subsequent treatments will be needed to exhaust the seed bank.

Fire is often used to remove gorse biomass. However, burning gorse is potentially dangerous, as a stand of gorse can present a serious fire hazard under some conditions (Amme 1983, unpublished report cited by [37]) (see Fire hazard potential). Air quality regulations and issues of public safety on nearby rights-of-way may also limit the use of prescribed fire for gorse control. For effective and safe burning treatments, plan the burn to coincide with times of low fire risk. Consult with local fire department officials to plan the logistical details of the burn including appropriate weather conditions and safety precautions. Because of the potential hazards, King and others [45] recommend using fire for gorse management only in areas too large for manual or mechanical means. Gorse root crowns that are not destroyed in the burn will sprout unless physically removed or killed. Resprouts will not produce seed for at least a year [97], and may be dug out or removed with a weed wrench or killed with herbicides applied within about 6 months after the burn. Moist soil facilitates removal of burned gorse [45].

Fire has been used to reduce numbers of gorse seed in the soil, primarily through the flush of germination that occurs following burning (see Plant Response to Fire). Gorse seedlings that emerge after fire must also be controlled with repeated burns or other follow-up treatment annually until the seed bank is depleted. With reduced seedling survival, burning gorse-infested sites about every 5 years may reduce gorse abundance ([37,69], and references therein). This approach is probably only effective in plant communities adapted to frequent fires. Native shrubs and trees should be planted after burning if native vegetation is not vigorous enough for reestablishment. Native vegetation may be able to outcompete the gorse with continued monitoring and eradication of newly established seedlings ([12,45], and references therein).

The use of fire in conjunction with biological control is complicated because fire is likely to kill biological control agents ([45,69], and references therein). Grazing by goats for 2 to 3 years after fire has been shown to reduce gorse populations to negligible levels in pastures (Radcliffe 1985, as cited by [12]). Gorse regrowth was grazed extensively after fire in heathlands in England (Tubbs 1974, as cited by [70]).

The majority of literature on the use of fire to control gorse comes from New Zealand, where gorse thickets are cleared to make way for planting trees. These approaches usually include an intensive herbicide regime in combination with prescribed burning. Burning alone rarely kills established gorse plants, and burned branches are often left standing, obstructing planters. Herbicides and/or mechanical crushing may be used several months before burning to desiccate gorse biomass or increase surface fuel loads to increase gorse consumption, fire severity, and subsequent mortality of gorse ([3,11,45,98] and references therein). Observations indicate that effective herbicide treatment can also minimize, and ideally eliminate, postfire sprouting in gorse. To achieve this it is necessary to optimize the timing of spray applications, as well as to choose an appropriate chemical and spray formulation. Herbicide is most effective when applied after flowering is complete and the new season's growth averages about 1 inch (2.5 cm) in length [3]. The earlier practice was to spray gorse 3 to 4 months before burning, which tended to result in charred gorse stems rather than complete consumption and also resulted in greater postfire coppicing. Better results are achieved if the desiccant spray is applied 15 months before burning to give a longer period for drying out of the gorse stem ([3,98], and references therein). Ideally, gorse stem moisture content should be reduced below 40% to ensure a burn that will leave the area clear enough for respraying or planting [70]. Rolston and Talbot [74] examined the possibility of reduced basal sprouting in gorse by using preburn spray treatments that kill the whole plant rather than only desiccating foliage. Herbicide treatments desiccated the gorse, some more than others, and some plants were sprouting after herbicide treatment. The degree of stem destruction was positively related to the degree of desiccation before burning (r=0.76). Preburn herbicide treatment reduced postfire sprouting in gorse by 32% to 90%, depending on type and rate of herbicide used [74].

Sometimes gorse can be eradicated with repeated herbicide treatments following burning to kill gorse sprouts and seedlings [11]. Spraying gorse after wildfires in New Zealand resulted in 9% mortality of sprouts, 22% yellow-green sprouts showing no signs of new growth, and 69% of sprouts exhibiting new growth 6 months after spraying. The main effect of postfire spraying was to reduce the average height of postfire sprouts to 6 to 8 inches (15-20 cm) compared with unsprayed areas where sprouts averaged 21 inches (54 cm) [3]. Herbicides may be applied to coincide with the postfire seedling flush and the "natural" seedling flush to be most efficient. After 2 applications of selected herbicides, residual soil seed numbers were reduced to as few as 5% of prefire levels, and 17 months after burning, gorse ground cover was reduced to 3% to 5% (Zabkeiwicz unpublished, as cited by [98]). Studies on developing gorse seedlings have shown that as its physical character changes (i.e. leaves are replaced by spines), its susceptibility to herbicides decreases. Zabkiewicz [97] recommends spraying soon after fire, killing gorse and grass seedlings to maintain bare soil. This may induce further germination of gorse, and those seedlings can then be sprayed. A problem with postburn spraying of gorse in gorse/bracken mixtures is that postfire fern growth intercepts the chemicals intended for gorse [3].

Fire hazard potential: It is commonly reported in the literature that gorse has high concentration of volatile oils in its foliage and branches [15,64] and produces considerable biomass with abundant dead material in the plant's center [13,45,64], such that gorse stands are highly flammable [15,33,45,51,64], burn rapidly and with high intensity [12,24,38,45], and pose a serious fire hazard [13,32,36,64]. Relatively little research is available, however, that examines gorse fuel characteristics, and none from North America.

Gorse occurs in fire-maintained heathland in its native range, where elements of fire risk, fuel biomass, and fuel structure have been studied. As heathlands age, combustible material accumulates and increases fire risk [75]. Fire risk in tall heath, as judged by accumulated biomass, was appreciable 5 to 7 years after low-severity fire and 10 to 15 years after higher severity fire. In tall heath "critical fire-risk threshold" was represented by a biomass of about 50 t/ha and continuous horizontal structure [25]. Hely and Forgeard [31] studied the structure and seasonal moisture characteristics of aboveground biomass in gorse in tall heathland in France for 15 months to assess its fuel characteristics for fire propagation models. Aboveground biomass had a spatially heterogeneous distribution due to the layered pattern of the branches. This pattern creates an internal moisture gradient that decreases from the apex to the base of the plant, and varies according to plant phenology. New, green branches with a high moisture content occur at the top of the plant (upper strata), whereas woody branches with a lower moisture content occur near the ground (lower strata). Dry branches and spines, which produce most of the litter, are homogeneously distributed throughout the pant. Temporally, the layered pattern is homogeneous through the year and thus creates a constant fire risk. Soil organic horizons under gorse are temporally, spatially, and compositionally heterogeneous, and the distance form a plant has a significant influence on the depth distribution of the soil organic horizons [31]. Total phytomass of dead wood increases substantially with plant height, but does not show a seasonal trend [65].

Nunez-Regueira and others [58] measured calorific values (high heating value (HHV) and low heating value (LHV)) and determined flammability of gorse and other vegetation samples taken from shrubland in Spain during different seasons. Heating values (energy released per unit of combustible mass) of gorse were as follows:

Season	HHV (kJ/kg)	LHV (kJ/kg)
Spring	20,182.38±64.15 (0.32%)	5,724.55±24.81 (0.43%)
Summer	20,680.74±73.71 (0.36%)	6,327.94±29.86 (0.47%)
Fall	20,950.41±87.82 (0.42%)	6,901.35±37.33 (0.42%)
Winter	20,472.57±81.33 (0.40%)	5,720.51±30.90 (0.54%)

Flammability values (according to a model proposed by Valette 1988) were highest in summer and fall, and gorse had the lowest flammability of the species tested [58].

Egunjobi [22] measured biomass distribution in green shoot, dead shoot, stem, and roots of gorse over 3 years, beginning 6 years after fire in New Zealand. Prefire vegetation was dominated by a closed canopy of gorse, 6 feet (2 m) tall, with little light reaching the ground. Average rate of dry matter accumulation in the standing crop (all species included, with gorse dominant at >80% cover) was 11,780 kg/ha in 1966, and 9,790 kg/ha in 1967. Mean annual litter fall in these communities over these 2 years was 8,880 kg/ha. Biomass distribution and energy content in a 7 year old stand (burned in December 1959) were as follows [22]:

	Biomass (kg/ha)			Calorific value (cal/g dry wt)	Energy content (10^8 cal/ha)
	Dec-65	Jun-66	May-67		
Green shoot	10,020	12,200	17,000	5,070	862
Dead shoot	2,260	2,550	3,330	5,260	175
Stem	14,760	41,500	35,600	4,770	1,698
Root	4,830	9,040	9,000	4,840	436
Total	31,870	65,290	64,930	---	3,171

Maximum frequencies (%) of different plant fractions in each of 3 height classes of gorse (I = 0-30 cm, II = 31-90 cm, III = 91-150 cm) were compared by season in gorse shrubland in northwest Spain [65]:

	Spring			Summer			Fall			Winter		
Height class	I	II	III	I	II	III	I	II	III	I	II	III
Plant fractions												
Green	76.7	62.5	78.3	86.0	81.7	36.7	69.2	49.2	57.5	76.7	41.7	44.2
Wood	10.7	45.0	42.5	20.0	64.2	40.8	23.3	40.0	42.5	18.7	45.0	42.5
Reproductive	30.0	42.5	50.8	0.0	1.7	1.7	0.0	0.0	0.0	0.7	5.8	8.3
Dead	16.0	65.8	69.2	11.3	81.7	61.7	45.0	50.0	75.0	18.0	74.2	61.7

The only reference to fire behavior in gorse in North America suggests that gorse fueled the wildfire, and was one of the obstacles to control, that burned down the town of Bandon, Oregon, in 1936, killing 13 people [38,52]. Fogarty [24] describes 2 wildfires in New Zealand, where the predominant fuel type was gorse. Both occurred during conditions of "High" forest fire danger, and on steep slopes (30-35 degrees), during strong winds (20-25 km/h). The gorse at both sites was dense enough to restrict firefighter access. The McEwans Fire (6 February, 1994) was on steep slopes and exhibited extreme fire behavior with a head fire spread rate of 4,440 m/h (+ 360 m/h) and a fire line intensity of 60,000 kW/m. This fire burned in 7- to 8-foot (2-2.5 m) tall gorse under 7-year-old pine that had been partially thinned and pruned. Samples from gorse of similar height and cover suggest that available fuel loads were at least 30 t/ha (G. Pearce and L. Fogarty, unpublished data, as cited by [24]). The Montgomery Crescent Fire (1 March 1994) had a rate of spread of 3,400 m/h (+ 550 m/h), and a fire line intensity of greater than 25,000 kW/m. Gorse plants were shorter at the Montgomery fire, and the pre- and postburn fuel measurements indicated that approximately 17 t/ha was consumed by the fire [24].

These fires occurred at the rural/urban interface, and issues of suppression, safety of residents, and firefighters, and other fire management issues are discussed in this report. "While no adequate Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992) exists for fires burning in gorse, it is apparent from numerous observations and some limited experimental burning (G. Pearce and L. Fogarty, unpublished data, as cited by [24]) that these fuels are exceptionally flammable and capable of sustaining extreme fire behavior at Low to High forest fire danger conditions" in New Zealand [24]. In a survey of firefighter fatalities, injuries, and near misses in New Zealand, at least 20 out of the 34 cases reported involve fire fighters being trapped in dangerous situations because of a fire run or wind change. Over 50% of these fires were in gorse. The author suggests clearing fuels to create at least 130 feet (40 m) of defensible space in the most likely direction of fire spread to increase the probability of house survival on home sites characterized by steep slopes and gorse (Millman 1993, as cited by [24]).

Similarly, in Australia high fire danger occurs in areas where nonnative shrubs form dense, tall, flammable undergrowth below sclerophyll forests. Gorse is a major fire hazard, because of its dense, dry growth from the previous season. When this shrub layer burns it ignites the sclerophyll tree canopy. Fire in these communities in summer may be impossible to control and is likely to result in a dense sward of seedlings [13].

Effects of gorse fire on other ecosystem properties: In its native range in Spain, researchers have examined the effects of burning heathland dominated by gorse on various ecosystem properties including nutrient inputs and losses, and moisture availability [80,81,82].

Availability of nutrients in ash is governed by temperatures reached during combustion, and by characteristics of vegetation and elements. Elemental analysis of gorse ashes gave the following results [81]:

C(%)	N(%)	Na (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	P (mg/g)	pH (1:1000)
7.35	1.11	157.66	92.15	27.52	45.12	29.20	11.10

Leaching of nutrients increased with increasing soil-exposure temperature, up to 860 °F (460 °C), then dropped at higher temperatures [81].

In some ecosystems there is concern regarding nutrient losses resulting from frequent fire. Nutrients lost from gorse scrub during burning and subsequent effects on nutrient input and output, through surface and subsurface runoff and soil erosion, were examined. Between 50% and 75% of nutrients contained in plant tissues were lost through combustion, and small amounts (3%) were deposited on the soil surface as ash. During the first rains after burning, nitrogen (N), phosphorus (P), and potassium (K) losses were largely due to sediment transport in surface runoff, while calcium (Ca) and magnesium (Mg) losses were due to both sediment and soluble-form losses (surface and subsurface flow). Nitrogen losses were largely in soluble form. Postfire nutrient inputs to the soil in throughfall were lower than in the control plots for N and K, while the remaining elements differed little between burn and control plots. In general, burning led to clear net losses of nutrients, whereas inputs and outputs were approximately equal in control plots [80].

Soil moisture distribution is modified by fire due to an increase in throughfall with removal of vegetation, an increase in evaporation in the surface soil, and a decrease of transpiration from deep soil layers. Effects of fire on throughfall and soil moisture were evaluated in gorse-dominated heathland in Spain. Throughfall in mature gorse shrubland is about 35% to 50% of gross rainfall. Water volume reaching the soil was significantly increased in burned plots during the first 2 years, where throughfall was 50% higher in burned plots than in control plots. Throughfall then declined gradually until it was similar in both burned and unburned plots by the 4th postfire year. Increased vegetation cover beyond the 4th postfire year did not create further reductions in throughfall. Removal of vegetation cover in gorse scrub by fire mainly affected subsurface water flows. Surface runoff increased after fire but did not entirely account for the increase in throughfall. Overall, soil moisture was higher in burned plots than in unburned plots. Water extraction from deep layers of soil in burned plots was mainly due to gorse sprouting from the root system. Use of the old root system by sprouting vegetation leads to a soil water profile in which 20 months after the fire the soil water is similar in burned and unburned areas [82].

MANAGEMENT CONSIDERATIONS

SPECIES: Ulex europaeus

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

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IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Gorse is cultivated in France as reserve livestock forage and was introduced to New Zealand as domestic sheep and goat forage ([45,70] and references therein). No other information is available on the use of gorse by livestock or wildlife.

Palatability/nutritional value: Gorse is spiny and mostly unpalatable when mature. However, gorse was readily eaten by domestic goats and sheep in indoor preference trials, although in the field only soft growth is eaten by sheep. Trials examining goat and sheep preference for browse species in mixed browse and pasture conditions in New Zealand tested 10 browse species. Two variants or ecotypes of gorse were tested: gorse and "short spine" gorse (an ecotype with shorter spines and a denser bush than typical gorse). Goats and sheep had a high preference for short spine gorse, and a low preference for typical or "wild" gorse [59]. Similarly, 11 shrubs were evaluated for their potential as browse species, and wild gorse was among the 3 species with the most potential as browse species in New Zealand hill country [48].

Nitrogen and element concentrations in leaf and stem material are presented here [48]:

Variant	Plant part	N*	P	K	S	Ca	Mg	Na	Cu	Fe	Mn	Zn	Si
wild gorse	leaf	1.9	0.11	1.0	0.13	0.32	0.13	0.25	3.8	91	64	43	7.6
	stem	1.3	0.08	0.9	0.11	0.28	0.12	0.28	4.6	84	43	48	10.7

short-spined gorse	leaf	2.2	0.12	1.1	0.15	0.43	0.22	0.55	5.9	119	107	42	7.8
	stem	1.3	0.09	0.7	0.13	0.47	0.20	0.44	5.9	75	52	31	16.8

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

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin (ADL) concentrations (%) in leaf, stem, and total foliage were as follows [48]:

Variant		NDF	ADF	ADL
wild gorse	Leaf	64	46	14.9
	Stem	72	52	14.6
	Foliage	65	48	14.9
short-spined gorse	Leaf	58	40	16.3
	Stem	66	42	12.6
	Foliage	63	41	15.7

Cover value: No information is available on this topic.

OTHER USES:
In its native range, gorse has long been cultivated for livestock forage and hedgerows ([37,45,70] and references therein). It has been suggested that gorse is useful on mine reclamation sites, and as a nurse plant for regeneration of native forest in New Zealand. It is a source of several chemicals used for medical purposes, and a major source of pollen for the honey industry ([70] and references therein). Gorse has potential as a renewable energy source [58].

IMPACTS AND CONTROL:
Impacts: Gorse is ranked by the California Invasive Pest Plant Council as one of the most widespread and invasive wildland pest plants that displaces natives and disrupts natural habitats [9].

Several reviews indicate that once established, gorse tends to dominate an area, excluding desirable vegetation including some threatened plants. In logged areas gorse may impede growth of desirable conifer seedlings and interfere with forestry operations [12,15,37,45,64]. It is impossible to walk through spiny gorse stands, and gorse can prevent livestock and wildlife access to some areas. Gorse is difficult to control, and often infests sensitive habitats or rugged terrain where control treatments are cost-prohibitive [15]. Where soil is bare between individual gorse plants, soil erosion may increase on steep slopes (Balneaves and Zabkiewicz 1981, as cited by [45]). Dense gorse stands may also pose a fire hazard (see Fire Ecology and Fire hazard potential).

As a nitrogen-fixing species, gorse has the potential to increase the total amount and cycling of nitrogen in invaded systems [55]. Increased nitrogen availability may reduce species diversity or otherwise alter plant community composition [19,55]. Additionally, nitrogen-rich litter from gorse may acidify the soil ([70], and references therein).

Control: Gorse is difficult to control because adult plants sprout from the stem and root crown following damage to aboveground parts, and because it establishes a large seed bank from which numerous seedlings establish, especially after disturbance. Repeated control efforts over several years are typically required to suppress gorse. Necessary management objectives for effective gorse control include inhibiting seed production, killing mature shrubs [97], and seed bank depletion [70]. New infestations should be treated before older ones, as younger plants are easier to remove and early eradication prevents build up of the soil seed bank. Remove gorse from roadsides to prevent spread by vehicles [64]. Gorse should be cleared to within at least 16 feet (5 m) of desired boundaries to prevent spread of gorse seed to adjoining areas [35].

Adult gorse plants can effectively be killed by pulling them out by the roots. However, this is not usually feasible for large infestations, nor is it appropriate in sensitive areas with species at risk, as it creates substantial soil disturbance [5,64]. Plants may also be killed by cutting off live stems 2 inches (5 cm) below ground level, or treating cut stumps with herbicide or mulch [64]. Treated plants must be monitored for sprouting, and new stems killed before they produce seed. Cut and uprooted plants should be removed from site to avoid fire hazard [64].

Management of seedling recruitment is particularly important in long-lived weeds such as gorse [69]. Heavy seedling emergence should be anticipated following any type of control effort, and seedlings should be allowed to sprout in order to deplete the seed bank in the soil [45]. Seedlings are easier to kill than adult shrubs and can be pulled (not cut, since cutting promotes sprouting) by hand before they reach 1.5 feet (0.5 m) tall, beginning the 1st or 2nd year after initial treatment, and repeated every few years [64]. Depleting the seed bank could take several years [45].

Gorse control requires a long-term commitment to monitoring and follow-up treatments to remove adult plants, sprouts, seedlings, and seeds in the soil seed bank [70,97]. It is important to monitor the distribution of gorse to prevent establishment of new populations [12]. Roads and treated areas should be surveyed at least once per year [64].

Prasad [64] describes a field experiment in Victoria, British Columbia, designed to test 4 control methods: a bioherbicide agent (*Chondrostereum purpureum*), a triclopyr herbicide, plastic mulch, and manual cutting. For all treatments adult gorse were 1st cut to stump height of less than 4 inches (10 cm). Applying herbicide to the stumps immediately after cutting was the fastest and most effective way of killing gorse. In the longer term, both mulching and herbicide treatments were effective and completely suppressed sprouting. The bioherbicide was slow acting and about 50% effective. Cutting gorse resulted in prolific sprouting on the stem from anywhere slightly below the root collar and upwards. Sprouting can occur on the stump as early as 3 weeks after cutting ([64] and references therein).

Several literature reviews offer more detailed summaries of control treatments for gorse including physical, biological, chemical, and cultural control treatments [12,45,70]. King and others [45] also describe a detailed approach for monitoring and record keeping strategies for managing gorse.

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 [78].

A review by King and others [45] recommends taking care to prevent soil disturbance, erosion or other degradation; and to prevent seed transport. They provide details on equipment care and cleaning to prevent gorse seed dispersal.

Integrated management: Gorse is best controlled by an integrated management program including monitoring, prevention, grazing by goats, manual and mechanical removal, revegetation, controlled burning, and spot treatments with herbicides. The choice of specific methods, timing, and combinations depends on the site conditions and the nature of the infestation [45]. All of the control approaches discussed in this review require some combination of approaches to be effective.

Physical/mechanical: A variety of physical and mechanical treatments have been used to control gorse, from hand-pulling of seedlings [64] to bulldozing large stands [32,37].

Gorse seedlings and young plants less than 5 feet (1.5 m) tall may be hand pulled, especially after rain has loosened the soil. Hoeing is also effective when plants are small. This method either cuts off the tops or exposes seedlings to the drying action of the sun [37]. Mulching may also be effective for controlling seedling emergence [64].

Large plants are more difficult to control with physical and mechanical approaches, and when effective can heavily impact the soil and lead to erosion and damage to desirable species [97]. A claw-mattock is effective in pulling out large plants and their root systems. Cutting of aboveground plant parts is only marginally effective, as it results in prolific sprouting. Cutting is a useful preparation for other methods, such as herbicide treatment of the cut stem, which can be very effective [32,64]. Repeated cuttings may help to exhaust the reserve food supply in roots, and is most effective when plants are beginning to flower [37]. In 1983 the San Mateo County Department of Parks and Recreation manually removed dense gorse from San Bruno Mountain, a task requiring approximately 350 person-hours per acre. Gorse was also removed by chaining with bulldozers and with the use of a bulldozer-mounted rototiller. Herbicides were used as a follow-up treatment (Reid 1985, cited by [37]).

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 [87] 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.

According to a review by Hoshovsky [37] there are no USDA approved insects for biocontrol of gorse. However, Coombs and others [14,15,16] discuss 3 insects, that have been either accidentally or purposefully introduced, that impact gorse. Several biocontrol agents have been released against gorse in Hawaii and New Zealand. Host specificity studies on these organisms have been partially completed (as of 2003) to determine whether they are safe to release on the U.S. mainland [15].

The gorse seed weevil (*Exapion ulicis*) was accidentally introduced into the United States in 1953 from France, and is now established in California, Hawaii, Oregon, and Washington, wherever gorse is found. It is not reported on the eastern U.S. coast. Larvae feed on growing seed inside gorse pods from April to June, and new adults emerge June to August. Adults feed on tissue under the cuticle of spines and stems, and may retard spread and invasiveness of gorse, but do not reduce established stand density. Redistribution is unnecessary, except where large areas of gorse have been destroyed by fire, after which the weevil may take several years to recover [14].

The gorse spider mite (*Tetranychus lintearius*) is also established in California, Hawaii, Oregon, and Washington, and is favored in open areas away from the ocean [16]. It is unclear how this mite was introduced to the U.S. Adult mites live in large colonies on terminal branches and produce large quantities of webbing. They pierce and extract cell contents from spines and stem tissue. Heavy stem damage by mites reduces flowering the following year. A predatory mite, *Phytoseiulus persimilis*, reduced extensive gorse mite colonies by more than 95% in 1 season in Oregon. At many sites a predatory coccinellid has also caused severe declines in gorse spider mite populations. As a result of so much predation, the mite has been rendered a more or less ineffective biological control agent in most areas [16].

An accidentally introduced moth (*Agonopterix nervosa*) that feeds on Scotch broom flowers, also damages growing twigs on gorse, causing short-term stunting and making plants appear more full and bushy [15].

Grazing by goats and sheep has been used for gorse control in some areas. In a long-term study, the best control of gorse was achieved by 1st burning gorse stands, followed by grazing goats or a 2:1 mix of goats and sheep at 25 or more animals/ha. Sheep alone did not control gorse. Once gorse plants were eradicated by goats and a dense pasture established, sheep alone could maintain the land gorse-free for 5 years. Where gorse was well-controlled but not eradicated, subsequent grazing over 5 years with goats and/or sheep allowed gorse to spread slowly. On similar areas of unburned gorse, sustained goat stocking eradicated gorse plants in 4 or 5 years with no regeneration from stumps after 3 subsequent years of sheep-only grazing [66].

Gorse seedlings may be susceptible to control with grazing management when competitive species are present. In a laboratory study, 4 defoliation treatments were tested in gorse seedlings at 2 growth stages, 4 and 8 weeks after sowing. All seedlings died with complete defoliation at the 6 to 9 trifoliate growth stage; however, at the cotyledon growth stage the remaining "stump" often sprouted, particularly when defoliation was close to the growing point. No seedling deaths were recorded in other defoliation treatments. Observations by the authors in the field suggest that a grazing intensity sufficient to defoliate seedlings below the cotyledons is difficult to achieve. Gorse seedlings appear to be adapted to defoliation, producing short shoots with a prostrate habit. Once the spines harden, control by grazing is likely to be less effective [73].

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 [8]. 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 [87] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals and adjuvants. Also see other reviews [37,97] for more detailed information on chemical control.

Mature gorse is difficult to kill with a single application of herbicide, and spraying alone is not a solution for gorse control [98]. However, several herbicides may be effective control options under some circumstances, in spite of the plant characteristics that do not favor herbicide retention and absorption. Performance of most herbicides tested was improved by addition of an adjuvant [7].

Applying herbicides that kill gorse plants and other vegetation creates suitable germination microsites for gorse, leading to an increase in the area covered by gorse unless herbicides are applied frequently [69]. Greater success is possible with a combination of methods, including crushing, cutting, and/or burning [32,37,97]. Herbicides are often used as part of intensive management programs in New Zealand (to prepare for tree planting) that include mechanical control and burning [5,11,74,98] (also see Fire Management Considerations). The operational sequence includes crushing or desiccating mature standing gorse with herbicide and allowing it to cure for at least 15 months before burning (usually in late summer). Postfire regeneration is then sprayed about 1 to 2 months after fire, and again the following spring/summer. Trees are then planted (about 15 months after the burn) and the site is sprayed again to control additional gorse seedlings [98]. Gorse seedlings are more susceptible to chemical controls than adult plants [37,97].

Cultural: Gorse can be suppressed by rapid growth of grass and by overstory trees, once they overtop the gorse [40,73]. Reseeding with native perennials after initial burning or chemical treatment of cut stumps may be effective. Once established, these species may displace gorse by competing for water or nutrients or by shading out lower-growing gorse plants ([37] and references therein).

In Oregon, Herman and Newton [32] advocate planting trees on gorse-infested land to form a dense stand of timber. The best preparation for planting was to burn gorse as completely as possible, and remove remaining stalks. Gorse seedlings and sprouts were then treated with herbicide for several years as trees established [32]

The success of competitive species depends on subsequent management. Fire must be excluded to avoid expansion of gorse (see Successional Status and Fire Effects). Early introduction of grazing may also result in a large reduction in gorse seedling numbers [40].

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