SPECIES: Bromus tectorum

Choose from the following categories of information.

INTRODUCTORY

SPECIES: Bromus tectorum





AUTHORSHIP AND CITATION:
Zouhar, Kris. 2003. Bromus tectorum. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2007, September 24].

FEIS ABBREVIATION:
BROTEC

SYNONYMS:
Bromus tectorum var. *glabratus* [121,195,226]

NRCS PLANT CODE [436]:
BRTC

COMMON NAMES:
cheatgrass
broncograss
downy brome
downy chess
soft chess

TAXONOMY:
The currently accepted scientific name for cheatgrass is *Bromus tectorum* L. (Poaceae) [106,165,174,200,211,222,267,358,375,451].

LIFE FORM:
Graminoid

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
As of this writing (2003), cheatgrass is classified as a noxious weed or weed seed in 2 states in the U.S. and 3 Canadian provinces [437]. See the Invaders or Plants databases for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: Bromus tectorum

GENERAL DISTRIBUTION:
The native range of cheatgrass encompasses much of Europe, the northern rim of Africa, and southwestern Asia [246,321]. Cheatgrass can now be found throughout most of Europe to southern Russia and western Asia. It has also been introduced to North America, temperate South America, Japan, South Africa, Australia, New Zealand, and Iceland [321,438,492].

The introduction of cheatgrass to North America probably occurred independently, several times, via ship ballast, contaminated crop seed, packing material and at least 1 deliberate introduction for a college experiment in Pullman, Washington, in 1898 [321,438]. By the early 1860s, cheatgrass had been identified in the U.S. in New York and Pennsylvania [235,492], and by the early 1900s, cheatgrass was present in much of its current range, though it was sparsely distributed [261,470]. Early infestations were commonly found near wheat (*Triticum aestivum*) cropland and railroads [307]. Once introduced, cheatgrass spread into adjacent rangeland in areas where it was adapted to local environmental conditions. Its expansion was especially rapid in parts of the Intermountain West, where its introduction followed a period of excessive livestock grazing in an ecosystem comprised of native plants that apparently did not evolve with heavy grazing pressure [261,307].

Cheatgrass now occurs throughout most of the U.S., Canada, Greenland, and northern Mexico [307]. It has been found in all Canadian provinces, and its range extends into Alaska and Yukon. In the eastern U.S. cheatgrass is mainly a roadside weed [438]. It is a "common invader" in the northern Great Plains [324]. Cheatgrass is most prominent and invasive in the Intermountain West, west from the Rockies to the Cascades and Sierra Nevada and north from central Utah, Nevada, and northeastern California to Canada. It is especially invasive in sagebrush (*Artemisia* spp.) steppe and bunchgrass regions in the Great Basin, Columbia Basin, and Snake River Plains in Nevada, Utah, Washington, Oregon, and Idaho [307,438,461]. The number and size of infestations in these regions has increased dramatically over the last 20 years [307]. Plants Database provides a distributional map of cheatgrass in the United States and Canada.

The following table presents acres of BLM-administered rangelands either infested or at risk of infestation by cheatgrass in a 5-state area as of 1992 (adapted from [337]):

State	Cheatgrass monoculture (>60%*)	Major understory component (10-59%*)	Potential future dominant (<10%*)
Idaho	1,082,880	1,751,040	1,221,120
Nevada	1,004,000	9,006,000	40,000,000
Oregon	437,760	2,004,480	9,169,920
Utah	297,600	1,082,880	11,635,200
Washington	85,500	142,500	72,000
Total	2,822,240	13,844,400	62,026,240

*Percent values refer to the estimated composition of cheatgrass by weight in the plant community

The National Science and Technology Center mapped about 31.5 million acres (12.7 million ha) of cheatgrass in the Great Basin from 2000 satellite imagery, about 6.7 million acres (2.7 million ha) of which was in "non-vegetative" areas (i.e. agriculture, urban, water and barren) [282].

Specific information on the plant communities in which cheatgrass may be found is limited outside its primary area of occurrence, where it is found mostly on abandoned cropland, roadsides, and "waste places." The following lists reflect ecosystems and cover types in which cheatgrass is most common and invasive, and are not necessarily exhaustive or definitive.

ECOSYSTEMS [163]:
FRES17 Elm-ash-cottonwood
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine
FRES23 Fir-spruce
FRES25 Larch
FRES26 Lodgepole pine
FRES28 Western hardwoods
FRES29 Sagebrush
FRES30 Desert shrub
FRES33 Southwestern shrubsteppe
FRES34 Chaparral-mountain shrub
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES38 Plains grasslands

FRES39 Prairie
FRES40 Desert grasslands
FRES42 Annual grasslands

STATES:

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

AB	BC	MB	NB	NS	ON	PE	PQ	SK	YK

MEXICO

BLM PHYSIOGRAPHIC REGIONS [44]:
1 Northern Pacific Border
2 Cascade Mountains
3 Southern Pacific Border
4 Sierra Mountains
5 Columbia Plateau
6 Upper Basin and Range
7 Lower Basin and Range
8 Northern Rocky Mountains
9 Middle Rocky Mountains
10 Wyoming Basin
11 Southern Rocky Mountains
12 Colorado Plateau
13 Rocky Mountain Piedmont
14 Great Plains
15 Black Hills Uplift
16 Upper Missouri Basin and Broken Lands

KUCHLER [248] PLANT ASSOCIATIONS:
K005 Mixed conifer forest
K010 Ponderosa shrub forest
K011 Western ponderosa forest
K012 Douglas-fir forest
K013 Cedar-hemlock-pine forest
K014 Grand fir-Douglas-fir forest
K016 Eastern ponderosa forest
K017 Black Hills pine forest
K018 Pine-Douglas-fir forest
K019 Arizona pine forest

K020 Spruce-fir-Douglas-fir forest
K021 Southwestern spruce-fir forest
K022 Great Basin pine forest
K023 Juniper-pinyon woodland
K024 Juniper steppe woodland
K025 Alder-ash forest
K026 Oregon oakwoods
K027 Mesquite bosques
K028 Mosaic of K002 and K026
K029 California mixed evergreen forest
K030 California oakwoods
K031 Oak-juniper woodland
K032 Transition between K031 and K037
K033 Chaparral
K034 Montane chaparral
K035 Coastal sagebrush
K036 Mosaic of K030 and K035
K037 Mountain-mahogany-oak scrub
K038 Great Basin sagebrush
K039 Blackbrush
K040 Saltbush-greasewood
K041 Creosote bush
K042 Creosote bush-bur sage
K043 Paloverde-cactus shrub
K044 Creosote bush-tarbush
K045 Ceniza shrub
K046 Desert: vegetation largely lacking
K047 Fescue-oatgrass
K048 California steppe
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K053 Grama-galleta steppe
K054 Grama-tobosa prairie
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe
K057 Galleta-threeawn shrubsteppe
K058 Grama-tobosa shrubsteppe
K059 Trans-Pecos shrub savanna
K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass
K065 Grama-buffalo grass
K066 Wheatgrass-needlegrass
K067 Wheatgrass-bluestem-needlegrass
K068 Wheatgrass-grama-buffalo grass
K069 Bluestem-grama prairie
K070 Sandsage-bluestem prairie
K074 Bluestem prairie
K075 Nebraska Sandhills prairie

SAF COVER TYPES [151]:
209 Bristlecone pine
210 Interior Douglas-fir

212 Western larch
213 Grand fir
215 Western white pine
217 Aspen
218 Lodgepole pine
219 Limber pine
220 Rocky Mountain juniper
221 Red alder
222 Black cottonwood-willow
227 Western redcedar-western hemlock
233 Oregon white oak
234 Douglas-fir-tanoak-Pacific madrone
235 Cottonwood-willow
236 Bur oak
237 Interior ponderosa pine
238 Western juniper
239 Pinyon-juniper
240 Arizona cypress
241 Western live oak
242 Mesquite
243 Sierra Nevada mixed conifer
244 Pacific ponderosa pine-Douglas-fir
245 Pacific ponderosa pine
246 California black oak
247 Jeffrey pine
249 Canyon live oak
250 Blue oak-foothills pine
255 California coast live oak

SRM (RANGELAND) COVER TYPES [390]:
101 Bluebunch wheatgrass
102 Idaho fescue
103 Green fescue
104 Antelope bitterbrush-bluebunch wheatgrass
105 Antelope bitterbrush-Idaho fescue
106 Bluegrass scabland
107 Western juniper/big sagebrush/bluebunch wheatgrass
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
201 Blue oak woodland
202 Coast live oak woodland
203 Riparian woodland
204 North coastal shrub
205 Coastal sage shrub
206 Chamise chaparral
207 Scrub oak mixed chaparral
208 Ceanothus mixed chaparral
209 Montane shrubland
210 Bitterbrush
211 Creosote bush scrub
212 Blackbush
214 Coastal prairie

215 Valley grassland
216 Montane meadows
301 Bluebunch wheatgrass-blue grama
302 Bluebunch wheatgrass-Sandberg bluegrass
303 Bluebunch wheatgrass-western wheatgrass
304 Idaho fescue-bluebunch wheatgrass
305 Idaho fescue-Richardson needlegrass
306 Idaho fescue-slender wheatgrass
307 Idaho fescue-threadleaf sedge
308 Idaho fescue-tufted hairgrass
309 Idaho fescue-western wheatgrass
310 Needle-and-thread-blue grama
311 Rough fescue-bluebunch wheatgrass
314 Big sagebrush-bluebunch wheatgrass
315 Big sagebrush-Idaho fescue
316 Big sagebrush-rough fescue
317 Bitterbrush-bluebunch wheatgrass
318 Bitterbrush-Idaho fescue
319 Bitterbrush-rough fescue
320 Black sagebrush-bluebunch wheatgrass
321 Black sagebrush-Idaho fescue
322 Curlleaf mountain-mahogany-bluebunch wheatgrass
323 Shrubby cinquefoil-rough fescue
324 Threetip sagebrush-Idaho fescue
401 Basin big sagebrush
402 Mountain big sagebrush
403 Wyoming big sagebrush
404 Threetip sagebrush
405 Black sagebrush
406 Low sagebrush
407 Stiff sagebrush
408 Other sagebrush types
409 Tall forb
411 Aspen woodland
412 Juniper-pinyon woodland
413 Gambel oak
414 Salt desert shrub
415 Curlleaf mountain-mahogany
416 True mountain-mahogany
417 Littleleaf mountain-mahogany
418 Bigtooth maple
419 Bittercherry
420 Snowbrush
421 Chokecherry-serviceberry-rose
422 Riparian
501 Saltbush-greasewood
502 Grama-galleta
503 Arizona chaparral
504 Juniper-pinyon pine woodland
505 Grama-tobosa shrub
506 Creosotebush-bursage
507 Palo verde-cactus

508 Creosotebush-tarbush
509 Transition between oak-juniper woodland and mahogany-oak association
601 Bluestem prairie
602 Bluestem-prairie sandreed
603 Prairie sandreed-needlegrass
604 Bluestem-grama prairie
607 Wheatgrass-needlegrass
608 Wheatgrass-grama-needlegrass
609 Wheatgrass-grama
610 Wheatgrass
611 Blue grama-buffalo grass
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass
615 Wheatgrass-saltgrass-grama
701 Alkali sacaton-tobosagrass
702 Black grama-alkali sacaton
703 Black grama-sideoats grama
704 Blue grama-western wheatgrass
705 Blue grama-galleta
706 Blue grama-sideoats grama
707 Blue grama-sideoats grama-black grama
712 Galleta-alkali sacaton
718 Mesquite-grama
720 Sand bluestem-little bluestem (dunes)
721 Sand bluestem-little bluestem (plains)
722 Sand sagebrush-mixed prairie
724 Sideoats grama-New Mexico feathergrass-winterfat

HABITAT TYPES AND PLANT COMMUNITIES:
Cheatgrass is most widespread in sagebrush steppe communities of the Intermountain West [492]. Daubenmire [406] considered cheatgrass a naturalized part of the vegetation in these communities as early as 1942. Many of the ecosystems that cheatgrass has invaded are seriously altered, and no longer support the vegetation of the potential natural community. Cheatgrass can maintain dominance for many years on sites where native vegetation has been eliminated or severely reduced by grazing, cultivation, or fire (e.g. [96]) (also see Successional Status). The concept of potential natural communities based only on native species is seriously challenged by cheatgrass. Where cheatgrass is highly adapted, it might have to be recognized as a component of the potential plant community [167]. In these situations, cheatgrass may remain the de facto climax dominant, regardless of site potential. The following discussion focuses primarily on component species of potential natural communities that cheatgrass has invaded, from low-elevation salt-desert shrub communities in the southern Great Basin [254,454,496] into higher-elevation juniper (*Juniperus* spp.), pinyon-juniper (*Pinus-Juniperus* spp.), pine woodlands, and the coniferous forest zone of the Rocky Mountains [210,307,487,492].

According to Stewart and Hull [406] in 1949 and Beatley [37] in 1966, only a few cheatgrass plants were found in black greasewood-shadscale (*Sarcobatus vermiculatus-Atriplex confertifolia*) and salt-desert shrub associations. Today, cheatgrass is common in these communities [50,53,59,76,181,214,254,454,457,487,491,496], especially in wet years [29]. Associated species may include budsage (*Artemisia spinescens*), bottlebrush squirreltail (*Elymus elymoides*), Sandberg bluegrass (*Poa secunda*), and Indian ricegrass (*Achnatherum hymenoides*) [50,52]. Cheatgrass also occurs with blackbrush (*Coleogyne ramosissima*) [59,82,185], galleta (*Pleuraphis jamesii*) [457], and many other salt-desert species.

In the Intermountain West, and most specifically the sagebrush steppe and bunchgrass zones, cheatgrass occurs in and often dominates large acreages of rangeland where native dominants include big sagebrush (*Artemisia tridentata*), bluebunch wheatgrass (*Pseudoroegneria spicata*) [52,53,76,159,181,185,197,202,203,204,276,310,365,382,419,435,473], Thurber needlegrass (*Achnatherum thurberianum*) [473], needle-and-thread grass (*Hesperostipa comata*) [276,473], western wheatgrass (*Pascopyrum smithii*) [52,181,419], basin wildrye (*Elymus cinereus*) [52,473], Idaho fescue (*Festuca idahoensis*), rough fescue (*F. altaica*), bottlebrush squirreltail, low sagebrush (*Artemisia arbuscula*) [159,193,197,202,203,204,276,310,365,417,430], spiny hopsage (*Grayia spinosa*), and rabbitbrush (*Chrysothamnus* spp.) [53]. Cheatgrass often co-occurs with Sandberg bluegrass and/or bottlebrush squirreltail, and on some Nevada sites has replaced Indian ricegrass or blue grama (*Bouteloua gracilis*) [53,55]. By 1932 cheatgrass had replaced big sagebrush on burned-over areas in the Great Salt Lake region of Utah, and occupied these sites in dense stands associated with cutleaf filaree (*Erodium cicutarium*), rabbitbrush, broom snakeweed (*Gutierrezia sarothrae*), and several other relatively unpalatable species and annual weeds [342]. Cheatgrass invades sites dominated by silver sagebrush (*A. cana*) and blue grama in Wyoming [419].

Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*) and basin big sagebrush (*A. t.* ssp. *tridentata*) are the most xeric of the big sagebrush community types and are the most susceptible to invasion by cheatgrass. These communities are more likely to be converted to annual grasslands with increased fire frequency (see Fire Ecology or individual reports on big sagebrush subspecies in FEIS for more information) [78,290,382]. Stiff sagebrush (*A. rigida*) communities are often found in a depleted condition, dominated by threetip sagebrush (*A. tripartita*) and an herbaceous layer consisting mainly of cheatgrass and other annuals [431]. Cheatgrass occurs but usually does not dominate the more mesic and cooler sagebrush types characterized by mountain big sagebrush (*A. t.* ssp. *vaseyana*) [378,426], low sagebrush [430,496], and threetip sagebrush [428]. Cheatgrass codominates with black sagebrush (*A. nova*) on several sites in Nevada, where bottlebrush squirreltail may also codominate [52,54,55]. However, cheatgrass is not usually persistent in black sagebrush communities [429].

In pinyon-juniper and mountain brush lands, cheatgrass can be found growing among Rocky Mountain juniper (*J. scopulorum*) [181,417,421], western juniper (*J. occidentalis*) [127,159], singleleaf pinyon (*Pinus monophylla*) [148,254], Utah juniper (*J. osteosperma*) [52,148,193,242,254], Colorado pinyon (*P. edulis*) [193,312], Gambel oak (*Quercus gambelii*) [193,255,312], Emory oak (*Q. emoryi*) [449], antelope bitterbrush (*Purshia tridentata*) [119,127,159,310,473,475], curlleaf mountain-mahogany (*Cercocarpus ledifolius*) [119,159,254,365,473,475], skunkbush sumac (*Rhus trilobata*) [310,419], snowberry (*Symphoricarpos* spp.) [467,473,475], serviceberry (*Amelanchier pallida*), and mountain big sagebrush [185,473,475].

Cheatgrass is common in the ponderosa pine (*Pinus ponderosa*) zone throughout the West [6,110,115,159,181,185,201,207,255,276,312,466,467]. It may be found with Douglas-fir (*Pseudotsuga menziesii*) [87,110,115,255,401,402,403,466,467], and on dry sites in the grand fir (*Abies grandis*) forest zone [159]. Cheatgrass is restricted to dry and exposed areas in western redcedar-western hemlock (*Thuja plicata-Tsuga heterophylla*) associations [207]. It is uncommon in mature forest stands, and is usually found only after disturbance or on dry and exposed sites within forest zones [345,346].

Cheatgrass is found throughout California, and is the dominant annual grass on sagebrush rangelands on the Modoc Plateau in northeastern California and along the eastern Sierra Nevada to Owens Valley [492]. On the Modoc Plateau, large acreages are dominated by big sagebrush and cheatgrass. Where recurrent burning has eliminated the sagebrush, communities are dominated by rubber rabbitbrush (*Chrysothamnus nauseosus*) and cheatgrass. Cheatgrass can also invade low sagebrush communities in this area, but density of cheatgrass tends to be lower, and that of medusahead (*Taeniatherum caput-medusae*) higher, than in big sagebrush communities [309]. Cheatgrass is among several Mediterranean species that have replaced native perennials in California grasslands [391], although it is relatively rare in the annual rangeland communities west of the Sierra Nevada [492]. On the south slope of Mt. Pinos, California, cheatgrass is found in the understory of stands dominated by Jeffrey pine (*Pinus jeffreyi*), singleleaf pinyon, shrub live oak (*Q. turbinella*), white fir (*Abies concolor*), canyon live oak (*Q. chrysolepis*), and California black oak (*Q. kelloggii*) [442]. It is one of the most common species in the herb layer of forests dominated by Jeffery pine on the eastern, desert-facing slopes of the Sierra Nevada

[30]. Cheatgrass seeds were found in the seed bank of mixed chamise-desert ceanothus (*Adenostoma fasciculatum*-*Ceanothus greggii*) chaparral of different ages [495], and cheatgrass plants are found on burned sites in California chaparral dominated by Eastwood manzanita (*Arctostaphylos glandulosa*) [443]. In the Sierra San Pedro Mártir, Baja California, cheatgrass may be seen along the mountain meadow-mixed conifer forest fringe [296].

In British Columbia, cheatgrass is found in very dry, hot bunchgrass and interior Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) communities [257]. In southern British Columbia, Tisdale [423] recognized 2 cheatgrass communities, both developing under conditions of heavy livestock grazing. One is a cheatgrass-Sandberg bluegrass-needle-and-thread grass association that developed from a needle-and-thread grass-bluebunch wheatgrass-Sandberg bluegrass association in the middle grassland zone. The 2nd type is a Sandberg bluegrass-cheatgrass association, found in the upper grassland zone [423].

Cheatgrass is listed as a dominant or codominant species in the following community and habitat type classifications:

Oregon and Washington [159]
Oregon [223]
Nevada [50,51,52,54,55]
Idaho [382]

Cheatgrass is also a common cropland weed, especially in winter wheat and alfalfa (*Medicago sativa*) in the Pacific Northwest and Great Plains regions [476,492], and is common in abandoned fields [112,185]. It may also be found among riparian vegetation (e.g. [123,184,223,265,327,330]); and it dominates riparian meadows in Great Basin National Park, Nevada [185,394].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Bromus tectorum

GENERAL BOTANICAL CHARACTERISTICS:
The following description of cheatgrass provides characteristics that may be relevant to fire ecology, and is not meant for identification. It is based primarily on descriptions found in several reviews [84,235,307,420,438,492]. Keys for identification are available (e.g. [106,165,174,451]).

Cheatgrass is a nonnative, typically winter annual grass [307]. It can assume a spring annual character when fall moisture is limiting and seeds germinate in spring [154,406]. Finnerty and Klingman [154] observed that cheatgrass plants germinating after April 1 in Lincoln, Nebraska, exhibited a biennial character, producing seed the following spring. Mack and Pyke [263] did not observe cheatgrass individuals with biennial character over 3 generations in eastern Washington. Production of 2 successive sets of inflorescences in a single growing season is, however, fairly common (see Seed production) [189]. Cheatgrass has a panicle inflorescence 2 to 8 inches (5-20 cm) long, open to more or less compact and drooping, with up to 8 spikelets, 1 to 2 inches (2-4 cm) long (including awns), with 2 to 8 florets per spikelet, and long straight awns attached to florets [307]. Fruits are caryopses. Leaves are 2 to 6 inches (4-16 cm) long and 2 to 4 mm wide [492].

Cheatgrass has a finely divided, fibrous root system with an average of 7 main roots that grow rapidly, spreading laterally and vertically. Cheatgrass roots can penetrate 34 to 60 inches (87-150 cm) or more, and are mostly concentrated in the top 12 inches (30 cm) of soil [186,199,207,398]. Plants 1st produce roots to depths of 7 to 8 inches (18-20 cm) before sending out far-reaching lateral roots. Cheatgrass reduced soil moisture to the "permanent wilting point" (about 4-8% soil moisture, dry weight basis) to a depth of 28 inches (70 cm) in natural stands , and to a depth of 40 to 50 inches (110-130 cm) in nitrogen-fertilized stands [207]. Cheatgrass roots are only thinly suberized as protection against loss of water to dry soil layers, which may explain why it dies earlier in summer than bluebunch wheatgrass and medusahead [189].

Cheatgrass grows rapidly, and may produce dry matter at a rate of 2.9 $g/mm^2/day$. Plants can mature with a single floret or with multiple tillers
and florets. The amount of growth or tillering depends on the amount and timing of moisture received [186,235], and varies widely from year to year, with practically nothing one year and tons per acre in other years [492]. Cheatgrass maintains its dominance on many sites by adaptations that facilitate early and rapid growth, including a type of carbohydrate metabolism that permits growth at relatively low temperatures [86]. Because cheatgrass can commence growth and deplete soil moisture before native plants break dormancy, it gains a competitive advantage in cold, semiarid environments [186]. This is evidenced by greater physiological stress and reduced total root length measured in perennial shrubs and grasses growing with cheatgrass than in plants growing without cheatgrass as a neighbor [280,281,446]. Cheatgrass also has greater top-growth yields per unit water used compared to summer-growing perennial grasses. This high water-use efficiency is partly due to early season growth, when transpiration rates are low [199,207].

Density of cheatgrass plants can range between 1 and 1,400 plants per square foot (3-15,000 per m^2), and averages around 600 plants per square foot (6,450 per m^2) [210,406]. Cheatgrass often grows in pure stands. Monocultures of thousands of acres with as many as 900 cheatgrass plants per square foot (10,000 per m^2) have been observed [484].

Cheatgrass is morphologically and phenotypically variable [207,235,272,319]. A common garden experiment by Hulbert [207] demonstrated the existence of several distinct ecotypes with differences in winter hardiness, phenology, height of culms, pubescence on lemmas, openness of panicles, and dorsal compression of florets. Cheatgrass exhibits considerable plasticity in its response to variation in site conditions. It may produce a single culm 1 to 4 inches (2.5-10 cm) tall and bearing only 1 spikelet when growing in a very dense monospecific stand, or on an infertile, droughty site. In contrast, where moisture, fertility or light intensity are not limiting, cheatgrass plants may produce 12-15 culms, 20 to 30 inches (50-75 cm) tall, bearing hundreds of spikelets [307,438].

Cheatgrass plants may be colonized by vesicular-arbuscular mycorrhizal fungi [45,171], with significantly higher ($p<0.05$) rates of colonization on ungrazed versus grazed range [45]. Cheatgrass is commonly infected with a head smut fungus (*Ustilago brominvora*) that can reduce stand density temporarily on some sites [288]. Smut infection is more common on north and east aspects on range sites in Montana [448].

RAUNKIAER [364] LIFE FORM:
Therophyte

REGENERATION PROCESSES:
Cheatgrass reproduces only by seed. Year-to-year variation in environment results in considerable variation in population attributes such as recruitment, survivorship, and fecundity. Cheatgrass can behave simultaneously on the same site as an ephemeral monocarpic, annual monocarpic and winter annual monocarpic species [263].

Breeding system: Cheatgrass has perfect flowers [184], is predominantly cleistogamous [320], and is usually autogamous [207,275,322] but can be xenogamous [420,487]. It has been suggested that the ability to crossbreed allows cheatgrass to adapt to differences in environment, and thus maintain its dominance and expand its range through selection of ecotypes that are highly competitive under different conditions [483,487]. Young and others [488] suggest that lodicule rigidity, anther exsertion, pollen vitality, and stigma exsertion and receptivity respond to increased environmental potential per individual (e.g. more nutrient and water availability and less competition following fire), thus improving the chances for crossbreeding in that generation.

Several authors provide evidence not only for phenotypic variation, but also for genetic variation within populations [272,285,360] and between populations [263,264,272,319,320,322,360]. Genetic variation tends to be greater between populations than within populations because cheatgrass has high levels of inbreeding [275,322], although Novak [319] found higher than expected genetic variation (for a self-pollinating species) within North American cheatgrass populations, citing the importance of multiple introductions. Populations of cheatgrass exhibit adaptive genetic variation corresponding to habitat [285,286,360]. Cheatgrass' success in a diverse array of environments has been attributed to its phenotypic plasticity, rapid growth of an extensive root system, ability to germinate and establish over a wide range of temperature and moisture conditions [317,322,361], and ability to adapt to different environments through incidents of crossbreeding [483,487].

Pollination: Cheatgrass is normally self pollinated [207,319] although cross-pollination can occur [420,487]. Young and others [487] suggest a postfire response in cheatgrass and a mechanism that would increase the likelihood for cross-pollination (see Fire ecology or Adaptations), although the vector(s) by which cross-pollination takes place are not given.

Seed production: In general, cheatgrass is a prolific seed producer. Hull and Pechanec [210] report natural seeding at an average rate of 70.8 million seeds per acre (177 million/ha), although seed production varies with plant density, time of germination, and environmental conditions [207,344]. Cheatgrass generally produces so many seeds that subsequent plant density is not related directly to the number of seeds present, but to the number of available sites in the seedbed capable of supporting germination [486]. Even during years with unfavorable growing conditions, cheatgrass can produce enough seed to perpetuate itself [207,424,492].

Reductions in density of cheatgrass populations can result in larger plants and a net increase in seed production [367,486]. Individual plants growing in high densities of about 1,000 plants per square foot (10,750/m^2) may produce about 25 seeds each; a large, open-grown plant can produce about 400 seeds; while a solitary cheatgrass plant with plentiful tillers and abundant moisture and sunlight can produce 5,000 seeds or more [343,487].

In general, seedlings that germinate in the fall and survive until maturity are larger than spring-germinated plants and produce more seed [207,263].

Certain environmental conditions can result in a 2nd seed crop in cheatgrass. Harris [186] observed scattered cheatgrass plants on a site in Washington that produced a 2nd seed crop from additional tillers during 2 consecutive springs. He also observed a stand of cheatgrass at the same location that produced inflorescences averaging 4 to 5 inches (10-12 cm) long during an unusually dry spring. After late spring rains, these drying plants greened-up and produced a 2nd, taller set of flowering stems. He noted that a similar response was observed at a site in Montana [186]. Similarly, Klemmedson and Smith [235] reported observations of a 2nd crop of cheatgrass seeds in the late spring at several locations in Idaho, and attributed it to the stimulation of new tiller growth by late spring rains after the cheatgrass had begun to senesce.

Seed dispersal:
Most cheatgrass seeds fall to the soil surface near the parent plant, or are spread short distances by wind or water. Long-distance dispersal is facilitated by humans and wild and domestic animals. The barbed florets are ideally adapted to being picked up by clothing, feathers, and fur [207]. Seeds can also be dispersed by machinery or vehicles [307,492]. Animals may carry cheatgrass seed in their feces and hooves [487]. Seed-caching rodents and harvester ants can disperse seeds intermediate distances through caching activity [111,313]. Mice cache cheatgrass seeds, sometimes resulting in dense, even-aged and short-lived tufts of

seedlings about 1 inch (2 cm) in diameter [111]. Seed predation by animals is not a major factor in reducing or controlling populations of cheatgrass seeds. In general, rodents, birds, and harvester ants have low preference for cheatgrass seeds when other species of seed are available. If granivores selectively avoid cheatgrass, its density may increase relative to other plants [355].

Cropland, particularly fields of winter wheat and dryland hay, may be potential seed sources to nearby natural areas and rangelands, as cheatgrass is a common weed in these crops. Cheatgrass seed may be dispersed in contaminated crop seed [438,492], or via animals passing through cropland. Cheatgrass seeds may remain viable for several years when stored dry within bales of hay or straw. Subsequently, transporting and feeding these bales to livestock can spread cheatgrass [307,492]. Early infestations of cheatgrass occurred along railroads when livestock cars used straw that was contaminated with cheatgrass seed for bedding [47].

Seed banking: Hulbert [207] found that cheatgrass seeds stored in paper sacks in a laboratory for 5.5 to 11.5 years had 95 to 100% germination in petri dish tests, suggesting a potential for seed banking. He concluded, however, that in the field, all or nearly all cheatgrass seeds germinate as soon as conditions are favorable, and that it is uncommon for seeds to remain viable but ungerminated for as long as a year. Since that time, a number of workers have observed that viable cheatgrass seeds lie over from 1 year to the next in the litter and soil [132,189,209,483,486], especially when seed production is so abundant that many seeds do not find safe sites for germination [492]. Seed bank density in cheatgrass varies with site characteristics, current and past vegetation, available microsites for germination, and history of disturbance.

Young and Evans [483] observed spatial and seasonal variation in density of germinable seeds of cheatgrass in the soil under and between canopies of big sagebrush. The maximum number of germinable seeds was present in the fall, and fewest in winter, although they did not sample in summer. Germinable seeds were found more often in the litter layer than in the underlying mineral soil, and more often under shrub canopies than in the interspaces. Between shrubs, 81% of the germinable seeds were located on the soil surface; there was virtually no litter other than the seeds themselves, which provided an environment conducive to germination [483].

Once cheatgrass has established on a site and gone through a couple of cycles of seed production and dispersal, the seed bank can contain 2 or 3 times as many viable cheatgrass seeds as there are established plants in the community [480,492]. Research by Billings [48] suggests a large viable seed bank for cheatgrass (about 106 seeds per square foot (1,177 per m^2)) in the top 6 inches (15 cm) of soil in an unburned sagebrush ecosystem in Nevada.

Upon dispersal, cheatgrass seeds are usually at least conditionally dormant, and lose dormancy through dry after-ripening [286]. Cheatgrass seeds that are dispersed in the seedbed in topoedaphic situations that are not favorable for germination may acquire dormancy [486]. Through the mechanism of acquired seed dormancy, cheatgrass has the ecological benefit of continuous germination [492], with some seeds remaining dormant and some germinating throughout fall and winter and into spring, and thus hindering short-term weed control treatments [486].

Cheatgrass seeds can remain dormant in the soil for 2 to 3 years, losing their dormancy slowly over time [147,483]. Because the breakdown is slow, prolonged wet periods with adequate temperatures for germination result in many more seedlings than when these seeds are exposed to short periods of ideal temperature and moisture conditions [147]. Germination of dormant seeds can be stimulated by nitrate enhancement of the seedbed [147,307,492]. Disturbances involving removal or destruction of plant biomass or mixing of soil typically increase nitrogen availability [400], which may enhance cheatgrass seed germination in the postdisturbance environment (e.g. [34,189]). While fire can kill most cheatgrass seed in the seed bank [192,213], surviving seeds tend to produce larger, more productive plants [488]. Thus, the cheatgrass seed bank can be replenished after a single growing season [192,213].

Daubenmire [112] and Tisdale [423] found that minimal amounts of cheatgrass were capable of establishment and discontinuous persistence in good- and excellent-condition bunchgrass communities in the absence of grazing. Young and Allen [478] suggest that the development of large, persistent seed banks allows cheatgrass to persist on these sites, where it does not otherwise have sufficient environmental potential to reproduce every year.

Germination:

Timing and success of cheatgrass seed germination is affected by light, temperature, and moisture conditions, the effects of which vary with the age of the seed, seed dormancy, and after-ripening requirements. In the field, patterns of germination response at dispersal vary between populations and across years within populations. Evidence of genetic control of seed germination regulation has also been given [285]. In one study, germination response differences between populations accounted for over 90% of the variance in germination traits, whereas differences within populations accounted for 1% or less of the variance observed. Cheatgrass seeds from predictable, extreme environments (subalpine meadow and warm desert margin) showed substantially less variation within populations than did seeds from less predictable environments (cold desert, foothill, and plains) [8].

Seedbed characteristics (e.g. litter coverage, microtopography, and soil texture) directly affect the microenvironment of the seedbed (e.g. light, temperature, and moisture) which, in turn, affects germination of cheatgrass seeds [141,142,482]. Germination of cheatgrass is inhibited on sites with well-developed biological soil crusts (which prevent seed burial) and low plant litter. Once seeds germinate, biological soil crusts show no barrier to seedling root penetration [43]. Cheatgrass seeds germinate best in the dark or in diffuse light [492]. Cheatgrass can establish on the soil surface in mesic parts of the northern mixed-grass prairie and Pacific bunchgrass biomes, but in drier environments cheatgrass requires environmental conditions less harsh than those of bare soil [488], and must be covered by soil or litter [142,146]. Details of temperature and moisture modifications created by differences in soil surface microtopography are given by Evans and Young [142] for both fall and spring emergence on clay and sandy loam soils with differing depths of burial. Often the seed mass provides the necessary litter for a portion of the crop to germinate [487]. Cheatgrass was even able to germinate in litter of singleleaf pinyon that inhibited the emergence of Sandberg bluegrass and Idaho fescue - apparently due to allelopathic effects [149].

Seeds germinate more quickly when covered with soil than with litter. Depth of burial is important, as demonstrated by Hulbert [207]: from the surface to a depth of 0.8 inch (2 cm) all cheatgrass seedlings emerged; a burial depth of 1.6 inches (4 cm) apparently eliminated some seedlings; and only a few seedlings emerged from a depth of 2.4 inches (6 cm). No emergence occurred from seeds buried 4 inches (10 cm) below the surface [492].

Newly ripened cheatgrass seeds germinate poorly at high temperature or in intense light [189], and seedlings that emerge in late summer and early fall are often killed by hot, dry weather later in the season [189,264]. In the Intermountain West, cheatgrass seeds typically germinate in response to autumn precipitation, but recruitment can occur at any time from autumn through late spring, within a few days after rain [189,207,235,262,263,307,486,492]. In the more mesic areas of the sagebrush-grass ecosystems, germination occurs in both spring and fall [146]. In the more arid portions of the Great Basin, cheatgrass rarely germinates in the fall, because by the time effective moisture is received, it is usually too cold for germination. In these areas, germination occurs in the early spring, and cheatgrass must complete its life cycle before soil moisture is exhausted [146,480,487]. It has been suggested that cheatgrass seeds may be induced into dormancy by low winter temperatures [448,483]. Young and Evans [483] found that by May this winter-acquired dormancy breaks down, and seeds begin germinating at a slow rate. Seedling emergence may be slow in spring, and spring-germinated plants are often smaller, less numerous, and less vigorous than fall-germinated plants [209,406].

Cheatgrass seeds germinate quickly and at very high rates (95% or more) when moisture and temperature conditions are favorable [209,307], and are relatively insensitive to moisture and temperature stress [170]. A review by Pyke and Novak [355] suggests that cheatgrass germination is uninhibited to a soil moisture of -1.5 MPa, although time to germination may increase as soil water potentials become more negative. Results presented by Goodwin and others [170] support this, as cheatgrass seeds began germinating in 1 to 2 days at 0 MPa and 2 to 5 days at -1 MPa. Allen and others [7] found that cheatgrass seeds were able to progress toward germination with intermittent hydration and dehydration episodes, although rate of germination was affected, particularly when dehydration occurred just prior to radicle emergence. A series of successive days of >1mm precipitation during autumn appears adequate for germination [355].

Cheatgrass seeds are highly germinable over a wide range of constant and alternating incubation temperatures [266], and a wide range of low and widely fluctuating seedbed temperatures. Cheatgrass seeds can germinate at temperatures just above freezing [142], and germination is inhibited by temperatures above 86 degrees Fahrenheit (30 °C) [189]. The optimum temperature for germination increases with seed age as follows: 50 degrees Fahrenheit (10 °C) for new seeds; 59 degrees Fahrenheit (15 °C) for 4-week-old seeds; 59 to 68 degrees Fahrenheit (15-20 °C) for 7-week-old seed; 68 degrees Fahrenheit (20 °C) for 1-year-old seed [207].

This and other evidence of an after-ripening requirement for cheatgrass seed germination (e.g. a retardation of germination with light observed in young seeds [207]), has been presented by several authors [9,38,39,207,286], suggesting that germination at the most favorable season is influenced by a mechanism involving changing reactions to light and temperature as seeds age. Allen and others [9] suggest that after-ripening is likely completed in late summer or early autumn regardless of summer conditions.

Cheatgrass seeds were nonviable after either ensiling for 8 weeks and/or rumen digestion by cattle for 24 hours. This rate of degradation during rumen digestion would result in an estimated 38 to 71% viable seeds (depending on the composition of the diet) following digestion by cattle [57].

Seedling establishment/growth:

Establishment of cheatgrass seedlings is favored by large amounts of plant mulch [141], although seedlings are relatively hardy with respect to surviving drought periods of up to 10 days [160].

Cheatgrass recruitment is usually concentrated in late summer and autumn, but can occur at any time until about mid-May. Mack and Pyke [263] observed almost continual recruitment of cheatgrass seedlings in Washington, such that even if fall and early winter recruits died without flowering, the late winter and spring emergents produced enough seeds to ensure another generation. Most plants survived to produce seed. Even individuals less than 45 days old produced at least 1 viable seed by June [263].

Cheatgrass establishment is favored at low temperatures compared to cultivars of crested and bluebunch wheatgrass [3]. It grows in a narrow range of soil temperatures, with growth starting just above freezing and stopping when soil temperatures exceed 60 degrees Fahrenheit (15 °C) [492]. Growth rate of cheatgrass increases from a low temperature limit of 37 to 45 degrees Fahrenheit (3-7 °C) to an upper temperature limit between 81 and 88 degrees Fahrenheit (27 and 31 °C). Beyond these limits growth ceases. These limits differ among subpopulations, and are related to the local microclimate. The optimum growth temperature is between 50 and 68 degrees Fahrenheit (10 and 20 °C) [272]. Cheatgrass can be extremely cold tolerant as indicated by plants surviving winter lows of -10 degrees Fahrenheit (-23 °C) in Minnesota with only very slight injury to leaves [207].

SITE CHARACTERISTICS:
Cheatgrass is adapted to a variety of climatic conditions [207,272,300,487]. While this has been largely attributed to its phenotypic plasticity [307,322], populations of cheatgrass may also exhibit adaptive genetic variation corresponding to habitat [285,286,360]. Cheatgrass' broad distribution reflects its ability to establish on a wide variety of sites, usually following disturbance. Its tendency to persist and expand on a site is governed by disturbance regime, temperature, moisture, soil, microtopography, and plant community characteristics.

Disturbance:

Often the critical factor opening niches for cheatgrass invasion is a heightened disturbance regime

[141,324,365]. Cultivation and subsequent land abandonment, excessive livestock grazing, overstory removal, and repeated fires can interact, or act singly, to proliferate cheatgrass [34,145,210,295,382,396]. Excessive grazing and frequent fires can damage biological soil crusts and many perennial plants, thus encouraging cheatgrass establishment, survival [43,71,488], persistence, and dominance [48,108,287,340,461]. In some cases, cheatgrass has expanded as a result of overgrazing, while in other cases intensive grazing has removed perennial grass fuels and reduced the ability of fire to spread, thus impeding the cheatgrass/fire cycle [2] (see Successional Status and Fire Ecology
for more information on the cheatgrass/fire cycle). A study in northern Utah indicates that cheatgrass is most invasive on mid-elevation sagebrush and shadscale sites on benches where livestock grazing and fires are common, and is less invasive on the higher-elevation sites where rugged topography and low water availability have resulted in less disturbance both by fire and livestock. Where fires have occurred at higher elevations, bunchgrasses have recovered vigorously with little cheatgrass invasion [397].

Cheatgrass invasion may be accelerated by disturbance, but disturbance is not required for cheatgrass establishment [167]. For example, disturbance is not a necessary precondition for invasion in intact shadscale-gray molly (*Kochia americana*) communities in Dugway Valley, Utah, but may facilitate the process in years with favorable moisture [287]. Cheatgrass can also thrive in areas that have little or no history of cultivation or grazing by domestic livestock [126,137,167,168,231,307,410,415]. It may establish in these relatively undisturbed areas when seed disperses from nearby patches and establishes on sites of small natural disturbances, such as where rodents or predators dig in the soil [37,179,207,365]. These cheatgrass plants may be small and weak with relatively low seed production [207].

Climate:

Cheatgrass grows under a range of climatic conditions. It can be found in salt-desert shrub communities that receive 6 inches (150 mm) of annual precipitation, and in high-elevation coniferous forests that exceed 25 inches (640 mm) of annual precipitation [111,307]. It tends to be most invasive in areas receiving 12 to 22 inches (300-560 mm) of precipitation that peaks in late winter or early spring [355]. Cheatgrass is well adapted to drier sites and is ubiquitous throughout the steppe environment of Washington, while Kentucky bluegrass (*Poa pratensis*) dominates in wetter habitats [111]. Cheatgrass is more invasive in Wyoming big sagebrush and pinyon-juniper belts than in cooler, more mesic sagebrush types characterized by mountain big sagebrush and low sagebrush communities above 5,280 feet (1,600 m) [168,426,427,430]. Mountain big sagebrush communities on warm exposures are more vulnerable to cheatgrass invasion. The ecotone between desert shrub communities and Wyoming big sagebrush communities is associated with 7 to 8 inches of annual precipitation (180-200 mm), while communities of typical mountain sagebrush are associated with greater than 12 inches (300 mm) annual precipitation [168]. In black sagebrush communities in central Nevada, cheatgrass was abundant only in years with adequate spring moisture [490]. Cheatgrass is well adapted to endure extreme drought, under which conditions plants produce little herbage but produce enough seed to establish another generation [406]. In recent decades, cheatgrass has begun to dominate many arid sites in salt-desert shrub and shadscale communities that have about 8 inches (208 mm) annual precipitation. It is thought that this occurred during a sequence of years of exceptionally high precipitation in the early 1980s. The probability that cheatgrass will invade and dominate these sites seems to depend on both weather patterns (i.e. amount and timing of precipitation) and seed availability [59,287].

Elevation:

Cheatgrass is most abundant between 2,000 and 6,000 feet (600-1,820 m) elevation in eastern Idaho, though it has been found at elevations up to 9,000 feet (2,700 m) [406]. Cheatgrass has been found at elevations of 13,100 feet (4,000 m) and above in the United States [214], and has been recorded at elevations up to 9,800 feet (3,000 m) in the Himalayas [438]. In 1966, Beatly [37] wrote that cheatgrass was confined to disturbed sites at higher elevations (5,000 to 7,500 feet (1,500-2,270 m)) on the Nevada Test Site in southern Nevada, where vegetation is dominated by sagebrush or pinyon-juniper, and that red brome (*Bromus madritensis* ssp. *rubens*) was the frequent dominant winter annual species in blackbrush communities at 4,000-5,000 feet (1,200-1,500 m). Cheatgrass has since expanded its range into lower elevation sites (e.g. [50,76,181,254,457,496]).

The following table provides some elevation and precipitation ranges for communities in which cheatgrass may be dominant or codominant, as reported by state or province. Cheatgrass is not, however, limited to these conditions.

State	Plant community dominants or codominants	Elevation	Mean annual precipitation	References
CO	Utah juniper/mountain snowberry (*Symphoricarpos oreophilus*)	7,200 feet (2,183 m)	----	[242]
ID	basin big sagebrush/cheatgrass	mostly below 7,000 feet (2,120 m); on south aspects as high as 7,800 feet (2,360 m)	----	[382]
NV	shadscale	4,320 to 5,400 feet (1,310-1,640 m)	6.7 to 11.4 inches (168-285 mm)	[52,53,54]
	spiny hopsage/green rabbitbrush (*Chrysothamnus viscidiflorus*)	5,250 to 5,500 feet (1,590-1,670 m)	8.4 inches (210 mm)	[53]
	black sagebrush	4,900 to 6,400 feet (1,485-1,940 m)	7.6 to 17.1 inches (190-428 mm)	[52,54,55]
	big sagebrush and various codominants	4,590 to 7,350 feet (1,390-2,230 m)	6.8 to 14.9 inches (170-373 mm)	[52,53,54,55]
	mountain snowberry-mountain big sagebrush/bluebunch wheatgrass	7,260 to 10,230 feet (2,200-3,100 m)	----	[434]
	Utah juniper	5,500 to 6,200 feet (1,670-1,880 m)	11.4 to 17.7 inches (285-443 mm)	[50,52]
	ponderosa pine/rubber rabbitbrush	5,600 to 5,900 feet (1,700-1,790 m)	16.6 inches (415 mm)	
	desert peach/shrub live oak (*Prunus andersonii*/*Quercus turbinella*)	6,125 feet (1,860 m)	16.7 inches (418 mm)	[55]
BC	big sagebrush, bluebunch wheatgrass	1,320 to 2,970 feet (400-900 m)	9 to 11 inches (230-270 mm)	
	ponderosa pine/bluebunch wheatgrass	1,650 to 1,980 feet (500-600 m)	11 to 15 inches (270-380 mm)	
	Idaho fescue-parsnipflower buckwheat (*Eriogonum	2,640 to 2,970 feet (800-900 m)	----	[276]

heracloides)	

Soils:

Cheatgrass will grow in almost any type of soil, but it does best on deep, loamy or coarse-textured soils (e.g. [125,256,492]). Medusahead may be more likely to dominate on fine-textured soils in the Intermountain West [481]. Cheatgrass is common on deep sandy soils associated with extensive big sagebrush stands on flat uplands and valley bottoms in mountain and foothill areas [37].

Cheatgrass can grow on calcareous and saline soils [53,54,276,455], although increasing soil salinity has detrimental effects on its photosynthesis and growth. A greenhouse study by Rasmuson and Anderson [361] suggests that cheatgrass' seed production and competitive ability may be impaired in environments where soil salinity is greater than about 4 dS/m in the rooting zone. Adverse effects were less pronounced on plants grown from seed taken from a population growing on a saline site [361]. Research by Billings [48] suggests that cheatgrass is not tolerant of acidic, nutrient-poor soils.

Cheatgrass can be competitive in low-fertility soils, and has been found growing on B and C soil horizons of eroded areas and on soils low in nitrogen [109,235,492]. Cheatgrass also does well on fertile soils where competition has been reduced [109,235]. Cheatgrass thrives and often dominates under conditions of increased nitrogen availability [109,186,189,258,478]. A study on an arid big sagebrush/Indian ricegrass site in Nevada indicates that nitrogen enrichment enhances density and biomass of cheatgrass, while immobilization of nitrogen favors establishment of Indian ricegrass [479]. It has been suggested that increases in nitrogen availability and in the abundance of NO_3^- relative to NH_4^+ play important roles in allowing cheatgrass stands to persist in much of the western United States [400,479]. Soil disturbance, fire, and atmospheric nitrogen deposition may contribute to increased abundance of introduced annual grasses, especially on infertile soils [72,107,400,408]. The cheatgrass/nitrogen relationship is not completely understood, and more research is needed to better understand these dynamics.

Aspect/topography:

In some ecosystems, aspect and topography can play an important role in cheatgrass establishment and dominance. In pinyon-juniper ecosystems in the Green River area in Utah [166,169] and on several sites in Nevada and California [243], cheatgrass tends to be more invasive on southern and western exposures than on northern exposures. In areas of sand dune knob and kettle topography in southeastern Washington, cheatgrass dominates south-facing slopes, whereas Sandberg bluegrass dominates north-facing slopes [369].

Cheatgrass establishes and dominates on sites with rough microtopography and litter [134,482,484]. Eckert and others [133] describe 4 soil-surface types and their influence on seedling emergence, revegetation, and secondary succession. Cheatgrass established under 1 and 2 inches (2.5 and 5 cm) of medusahead, cheatgrass, or bluebunch wheatgrass litter, but failed to establish under litter of any species at 3 inches (7.5 cm) [189]. In sagebrush steppe, cheatgrass seedlings often grow in dense, circular patches in the area directly beneath the canopy of shrubs. This may be related to burrowing activity of mice, to litter accumulation under shrub canopies [111], or to the large quantities of grasshopper frass that accumulate in the subcanopy of big sagebrush, which the grasshoppers roost in at night [113]. In shadscale communities, cheatgrass plants grow better under shrubs, which seem to act as nurse plants for cheatgrass by ameliorating growing conditions [287]. Similarly, cheatgrass often grows more luxuriantly near greasewood and spiny hopsage than in adjacent open ground [256,438]. Cheatgrass was rare in unburned transects and was found most frequently beneath the canopy of living trees in big sagebrush and pinyon-juniper communities in west-central Utah [329]. At another study site in Utah, cheatgrass had significantly ($p<0.05$) higher frequency under the canopies of Colorado pinyon and juniper trees compared with the interspaces at all tree densities [315]. On a western juniper site in central Oregon, cheatgrass production increased with increasing tree size in both the interspace and subcanopy zones [135].

Cheatgrass does not flourish in mature ponderosa pine, Douglas-fir, grand fir, or western redcedar forests of the

Intermountain West. The inability of cheatgrass to persist under these forest canopies is attributed to the influence of shade on the plants' photosynthetic rate and on resource allocation, the short growing season, and the role of herbivory in exacerbating the other factors. Consequently, these forest zones broadly define the current environmental limits of the distribution of cheatgrass in western North America [345,346].

SUCCESSIONAL STATUS:
Cheatgrass is a facultative seral species, acting as both an early seral invader and as a climax dominant on many sites that historically supported perennial grass and forb communities. Everett [148] suggests that in areas where cheatgrass is dominant or codominant, the habitat type or "potential natural community" may not be useful classifications due to severity of past disturbances and irreversible changes in the plant community over time. Instead one might consider the "most probable plant community" at a given site under specified circumstances. Cheatgrass is especially prevalent in the early stages of fire succession or following other disturbances when shrubs, trees, and perennial grasses are removed [34,139,145,210,291,295,382,396]. Cheatgrass' successional status varies with plant community composition, disturbance type, and disturbance history.

Cheatgrass can outcompete many other competitive nonnative plant species including halogeton (*Halogeton glomeratus*), tumblemustard (*Sisymbrium altissimum*), and Russian-thistle (*Salsola kali*) [120,344]. On some sites cheatgrass may be replaced by other highly competitive, nonnative, invasive species such as bur buttercup (*Ranunculus testiculatus*), forage kochia (*Kochia prostrata*) [198,476], common St. Johnswort (*Hypericum perforatum*), Dalmatian toadflax (*Linaria dalmatica*), yellow starthistle (*Centaurea solstitialis*), spotted knapweed (*C. stoebe* ssp. *micranthos*), diffuse knapweed (*C. diffusa*), squarrose knapweed (*C. virgata* ssp. *squarrosa*), rush skeletonweed (*Chondrilla juncea*), and leafy spurge (*Euphorbia esula*) [187] [374]. Northam and Callihan [318] also suggest that cheatgrass may potentially be replaced by other nonnative, annual grasses (e.g. interrupted windgrass (*Apera interrupta*), corn brome (*Bromus squarrous*), little lovegrass (*Eragrostis minor*), poverty grass (*Sporobolus vaginiflorus*), and ventenata (*Ventenata dubia*)) that are capable of invading and establishing in cheatgrass-infested areas.

Artificial seeding of nonnative (and sometimes invasive) perennial species such as crested wheatgrass (*Agropyron cristatum*) is commonly carried out following wildfire on managed lands to preclude the development of undesirable cheatgrass stands and to meet other management objectives [144,260,329]. A study in Utah followed vegetation changes for 3 years after wildfire and artificial seeding of desirable perennial species (mostly nonnative). Cheatgrass density increased steadily for 3 years following burning and seeding, unlike the seeded species [329].

Sagebrush steppe:

Cheatgrass is most invasive and persistent in sagebrush steppe and cold desert regions of the Intermountain West. Cheatgrass initially established in the Intermountain area with the introduction of livestock, which dramatically changed the balance between herbaceous understory and woody overstory species when intense grazing removed native bunchgrasses. There is a lack of native annual grasses, so cheatgrass fills that niche, and has truncated succession on many sites [111,159]. Results presented by Young and Evans [482] suggest that as long as there is a seed source and a suitable seedbed, cheatgrass will dominate on big sagebrush sites after removal of shrub overstory. They did not encounter an assemblage of native annual plants that was capable of preventing cheatgrass dominance on big sagebrush sites.

Cheatgrass can dominate the 1st or 2nd year after disturbance, and has dominated some sites for 40 to 80 years, even in the absence of further disturbance [48,93,114,167,236]. This suggests that communities dominated by cheatgrass are a permanent and widespread feature of the landscape in some areas [236]. Piemeisel [344] quantified the steps in succession from bare ground to cheatgrass dominance and reported that even rodent disturbance was sufficient to maintain cheatgrass dominance. On sites where a major shrub and/or bunchgrass component has not been eliminated by cultivation, fire, grazing, or herbicides, a shrub/cheatgrass or bunchgrass/cheatgrass climax community may occur [96,111,159]. When excessive grazing causes replacement of most perennial herbs by cheatgrass and other annuals, and when fire eliminates shrubs like big sagebrush and antelope bitterbrush, the percentage of rangeland dominated entirely by annuals progressively increases

[111,159]. On some sites essentially pure cheatgrass stands may be found [461]. A combination of burning and grazing can also result in annual rangeland dominated by cheatgrass and rubber rabbitbrush [116,159].

A common pattern of succession after disturbance in cropped and abandoned fields in the Great Basin and Snake River Plains begins with Russian-thistle and/or flixweed tansymustard (*Descurainia sophia*) and tumblemustard, followed by cheatgrass dominance within about 5 years [111,146,159,343,344,483,488]. Cheatgrass outcompetes tumblemustard and other broadleaf plants when sufficient litter has accumulated on the soil surface to allow for cheatgrass germination [146,344]. On some sites, cheatgrass may be pre-empted by foxtail fescue (*Vulpia myuros*), a native annual grass [483]. Abandoned fields in the bluebunch wheatgrass/Sandberg bluegrass habitat type quickly develop a dense stand of cheatgrass that may dominate, along with rubber rabbitbrush, for more than 40 years [111,114]. On heavily grazed or abandoned farmland in the common snowberry (*Symphoricarpos albus*)/Idaho fescue and Nootka rose (*Rosa nutkana*)/Idaho fescue zones, cheatgrass will ultimately give way to Kentucky bluegrass, and on some sites, medusahead [159]. In the sagebrush steppe in northeastern California, Russian-thistle, tumblemustard, and cheatgrass form a seral continuum that closes many sagebrush communities to the establishment of perennial seedlings. Medusahead has extended the seral continuum by replacing cheatgrass on some low sagebrush (*Artemisia arbuscula*) sites on the Modoc Plateau [309,481].

Medusahead can replace cheatgrass on some sites [295,381,475], especially moist sites [196] and those with fine-textured soils [187,198]. Over the past 40 years medusahead has replaced cheatgrass over extensive areas in the sagebrush zone in California, Idaho, Oregon, and Washington [196]. Medusahead litter impedes cheatgrass establishment, and medusahead may do better in low-nitrogen environments than cheatgrass [187,189]. Coexistence of cheatgrass and medusahead is most likely in habitats low in nitrogen and phosphorus. In more fertile habitats, cheatgrass is likely to have the competitive advantage unless other environmental factors (e.g. high clay content) favor medusahead [109].

Soils in sagebrush steppe habitats tend to be low in organic matter, low in available phosphorus and nitrogen, and have limited water availability; therefore, mycorrhizae can be important to native plants for acquisition of water and nutrients. Invasion by either nonmycorrhizal or facultative mycorrhizal plants such as cheatgrass can reduce populations of mycorrhizae, thus indirectly affecting successional dynamics in semiarid lands [171,464].

Postfire succession in sagebrush steppe:

Grazing and agricultural practices have disturbed many habitats, but each year, more sagebrush rangeland is converted to annual grass rangeland due to wildfires. The successional trajectory following fire depends on prefire plant community and seed bank composition, site fire history, fire severity, fire return interval, and livestock grazing practices before and after fire. With the many possible permutations of these variables, successional patterns are very site specific, although generalized patterns of the grass/fire cycle have been described as follows: 1st, dominant native perennial grasses and forbs are reduced by grazing, and sagebrush and rabbitbrush increase forming a dense canopy with little understory vegetation [340,461]. Or, cheatgrass establishes on a site and increases in density with "improperly timed" grazing or other disturbance [342]. Fire is carried through the community within the canopy or via cheatgrass fuels in the spaces between shrubs and/or bunchgrasses. Following fire, native species cover is typically reduced, and cheatgrass cover may increase or decrease, depending on prefire cheatgrass density and seed availability [340,342,461]. By the 2nd or 3rd postfire year, given sufficient moisture, cheatgrass cover may increase to the point where the site is closed to seedlings of perennial grasses [340,476,477,484]. It has also been suggested that an increase in intraspecific diversity in cheatgrass populations after fire can increase its adaptability and improve its chances for site dominance [484]. As cheatgrass dominance increases, so does the likelihood of fire, and within 3 to 6 years following the initial fire, the amount and continuity of fuels is usually sufficient (in the absence of grazing) to carry a 2nd fire. Successive fires become common, and each fire reduces the surviving shrub cover and native seed bank [340,342,461].

Associated native perennial species respond differently to fire. Native perennial seedlings are more likely to establish in wet years, as is cheatgrass. Bottlebrush squirreltail is more fire tolerant than the fescues or

wheatgrasses (Triticeae) [340,494]. The response of perennial forbs varies with season of burning, and most are more tolerant of fire in late summer [484]. Recovery of shrubs tends to be slow, and those present in the early stages of succession are primarily those that can sprout. These include diverse species and subspecies of rabbitbrush (*Chrysothamnus* spp.), and species of horsebrush (*Tetradymia* spp.), ephedra (*Ephedra* spp.), and *Prunus* [46,48,473,475]. Although rabbitbrush may initially increase with fire, it is killed when the fire-free interval decreases to 5 years or less [340,342,461]. Big sagebrush is the dominant species in vast areas of the Intermountain landscape, and none of the subspecies sprout after burning [473,475]. To allow establishment and persistence of many sagebrush species, the fire-free interval must be greater than 20 to 50 years [340]. This varies between the subspecies of big sagebrush, with Wyoming big sagebrush being the most fire sensitive, followed by basin big sagebrush, and mountain big sagebrush being the most fire resilient [425,426,427] (See Fire Ecology
or FEIS reviews on individual subspecies for more detail.) In annual grass dominated communities, the fire-free interval is likely to be about 10 to 12 years or less. With each successive fire, annual grass dominance is enhanced, and the fire-free interval is decreased. This results in a more homogenous landscape, decreased species diversity, and larger and more continuous burns [340]. According to state-and-transition models for sagebrush steppe presented by Laycock [251], fire, grazing, and annual invasion can lead to a threshold beyond which the steady state becomes an annual grassland. After such a threshold has been crossed, intensive human intervention may be necessary to bring the system to a state containing desirable perennial species.

Successional trends are not always predictable. An 11-year study on a Wyoming big sagebrush semidesert site in central Utah found that Wyoming big sagebrush was reduced and perennial bunchgrass cover increased on all burned plots. Cheatgrass cover increased for 2 years following fire, followed by a 2-year reduction in cover, and 3 years of considerable year-to-year fluctuation in cheatgrass cover. The final years showed a negligible presence of cheatgrass with and without livestock grazing. Lower-than-average rainfall during the last 4 years of the study may have played a part in the decline of cheatgrass, and the lack of repeated fire may have been important in the maintenance of perennial grasses [206]. On a sagebrush steppe site in Nevada that was ungrazed for 30 years, cheatgrass cover increased by 38% over those 30 years. Thurber needlegrass and bottlebrush squirreltail also increased (726% and 182%, respectively), and Sandberg bluegrass increased 8%. Perennial grasses as a whole increased 72%, and bluebunch wheatgrass was reestablishing naturally in favored spots [372].

Cheatgrass is less invasive in mesic environments, where it does not compete as effectively with established perennial grasses. It may be dominant only in early successional stages, and is eventually replaced by perennial species [40,277,307,448]. When mountain big sagebrush (the most mesic of the big sagebrush subspecies) is replaced by cheatgrass after fire, successional trends may be toward bottlebrush squirreltail and later bluebunch wheatgrass [378]. Cheatgrass may remain a minor component of later successional stages on these sites, occupying the interspaces between perennial plants [307].

Salt-desert shrubland: In many salt-desert shrubland sites dominated by species such as saltbush (*Atriplex* spp.), winterfat (*Krascheninnikovia lanata*), black greasewood, creosotebush (*Larrea tridentata*), and blackbrush, cheatgrass and other nonnative annual grasses (particularly red brome) have become dominant and altered successional pathways during the past few decades, primarily by changing fire regimes (See Fire Ecology
for more details). Populations of cheatgrass in these arid ecosystems are ephemeral and tend to follow precipitation patterns such that dense populations arise during the spring following a year with high precipitation [29,214,238]. The demise of dominant shrub species contributes to cheatgrass dominance [124,491].

Just as dominance of cheatgrass promotes fire in sagebrush steppe ecosystems, salt-desert ecosystems dominated by nonnative annual grasses are more flammable than those dominated by native species [69]. Following 2 or more years with above-average precipitation, sufficient fine fuel may be present to sustain a wildfire [238] and convert desert plant communities to cheatgrass indefinitely [339]. Generally, most native plant species in the deserts of North America are poorly adapted to survive fire [48,69,137]. In experimental fires in the Mojave, flames fueled by annual bromes were sufficient to consume small shrubs such as white bursage (*Ambrosia dumosa*), winterfat, white burrobrush (*Hymenoclea salsola*), and Anderson wolfberry (*Lycium andersonii*), but were usually insufficient to ignite larger shrubs such as creosotebush, unless the shrubs had large accumulations of grass litter and dead shrub stems in the subcanopy [69]. Species such as shadscale and budsage do not sprout following fire. Winterfat, saltbush, gray molly, and black greasewood do sprout, but plants appear less vigorous after fire [455]. Postfire dominance of annual grasses sets the stage for the grass/fire cycle to continue, with large areas converted to annual grasslands that may persist indefinitely.

Callison and others [83] studied 8 blackbrush sites in southwestern Utah that had been burned under prescription to remove blackbrush and "increase forage production" between 1 and 37 years previous. They found that sites were dominated by forbs 1 year after fire, dominated by annual grasses (cheatgrass or red brome) 2 to 17 years after fire, and dominated by shrubs 37 years after fire. Blackbrush showed no signs of recovery after 37 years [83]. Similarly, research by Matchett and Brooks [268] indicates that nonnative annual grasses (cheatgrass and red brome) have persisted as the dominant vegetation type, along with early successional shrubs, for up to 60 years after fire in some blackbrush communities. Successional trends are difficult to predict, however, as indicated by some sites where blackbrush has recovered to prefire conditions during the same time interval [268].

Pinyon-juniper:

In pinyon-juniper ecosystems in the Great Basin, cheatgrass most commonly occurs and has its highest cover in early to mid-successional stages [145,206,244,329,484]. Cheatgrass also frequently occurs in mature pinyon-juniper communities at low densities. Succession in Colorado pinyon-Utah juniper in the Green River corridor in Utah generally proceeds in the following pattern: grasses and forbs dominate early successional stages followed by shrubs (up to 50 years after fire), shrubs with open trees (60 to 100 years after fire), trees with understory shrubs (100 to 200 years after fire) and mature pinyon-juniper (200 years after fire until the next disturbance) [166]. As pinyon-juniper stands increase in density and approach crown closure, herbaceous cover [416] and seed production [150,245] decline. See Goodrich [166] for further descriptions of crown cover, stand structure, plant composition, and ground cover attributes that are representative of each stage.

Postfire succession in pinyon-juniper woodlands is largely dependent on the degree of crown closure of the overstory before disturbance. Recovery of native communities can be rapid following fire in the perennial grass/forb through the shrub/open tree stages. If burned before crown closure has eliminated the understory, the onset of precipitation and warm temperatures encourages native woody species to sprout and native seeds to germinate [166]. Because cheatgrass is nearly ubiquitous in these woodlands and native species are lacking in the understory and seed bank of mature stands, cheatgrass and other nonnative species are likely to invade and/or dominate early successional stages following disturbance in mature pinyon-juniper stands if sites are not artificially seeded [166,351,393]. Nonnative annuals may subsequently prevent perennials from establishing [77,148,149,166]. Annual cover, often dominated by cheatgrass, can increase rapidly, achieving ground cover closure of 60-80% in 5 to 10 years. This stage can persist for 20 years or longer, and may persist until pinyon and juniper return as dominants, or may be perpetuated by frequent fires fueled by cheatgrass. On some Colorado pinyon-Utah juniper sites with south aspects in the Green River corridor, cheatgrass has dominated for 80 years [167]. It has been suggested that with seeding, a perennial community can be well developed within 2 years even with a strong presence of cheatgrass [166].

Ponderosa pine, Douglas-fir, grand fir, and western redcedar forests: Grazing in ponderosa pine/Idaho fescue associations in northeastern Washington may cause an irreversible shift to understory dominance by cheatgrass and other nonnative invasive species such as Dalmatian toadflax and common St. Johnswort [115]. Cheatgrass is also an early seral invader after logging and grazing in the Douglas-fir/ninebark association on sites in northern Idaho, although it appears to decrease in cover as succession progresses and shade increases [87,88]. Cheatgrass is present in early successional stages after logging and burning in grand fir series in the Wallowa Mountains of Washington [159]. In Douglas-fir in south-central Idaho, cheatgrass established after fire and remained at 4-8% cover for 5 years and then increased to 20% cover, 6 and 7 years after fire [259].

Research by Pierson and Mack [345,346] in mature ponderosa pine, Douglas-fir, grand fir, and western redcedar stands suggests that cheatgrass is unlikely to spread and persist in these forest habitats unless the scale and incidence of disturbance is severe and frequent enough to prevent canopy closure. Establishment of cheatgrass in low-elevation ponderosa pine and Douglas-fir forests can be enhanced by disturbance that opens the understory, removes litter, or both. Cheatgrass is unlikely to establish in grand fir and western redcedar habitat types without simultaneous opening of the overstory and understory [346]. Surviving cheatgrass plants in these forest types tend to be small and produce few, if any, seeds. Cheatgrass appears to persist within these forest zones on open sites where temperatures rise sooner in spring and light is not limiting [345]. At least in part, cheatgrass is largely restricted to forest gaps because of its intolerance of shade. Shading cheatgrass reduces its rate of growth, number of tillers, and ability to replace leaf area lost to herbivory. These responses, in turn, intensify the effects of competition and defoliation on cheatgrass in forests [347].

SEASONAL DEVELOPMENT:
Cheatgrass phenology and biomass allocation vary between populations. Plants in arid steppe sites flower and set seed earlier that those from mesic steppe or forest habitats [366]. Cheatgrass is usually a winter annual [147]. Its seeds typically germinate in the early fall when moisture becomes sufficient. In southern Idaho, about 2 inches (50 mm) of concentrated early fall precipitation is required to stimulate about 2 to 4 inches (5-10 cm) of fall growth [210]. After fall germination, cheatgrass plants grow rapidly until cold temperatures arrive [438]. Cheatgrass seedlings emerging in late August to September may die during a period of dry, hot weather [186,263]. Seedling death rates decline with later-emerging seedlings, and few plants die during the winter and spring regardless of emergence date [263].

Cheatgrass roots often continue to develop during winter, while aboveground growth is minimal [46,186,189,235,307,492]. In mild winter weather, cheatgrass plants can tiller and produce many adventitious roots [189].

Harris [186] provides a detailed examination of root phenological development in cheatgrass, as compared with medusahead and bluebunch wheatgrass. He concludes that fall germination and winter growth, even at near-freezing soil temperatures, allows annuals to increase number and length of roots during winter so that by spring, they are in control of the site and exhaust upper profile moisture supplies to the detriment of bluebunch wheatgrass. Cheatgrass roots continue to grow at 37 degrees Fahrenheit (3 °C), while bluebunch wheatgrass roots remain dormant until soil temperatures reaches 46 to 50 degrees Fahrenheit (8-10 °C) in late April [186].

Studies in Washington and Idaho suggest the following sequence of development in cheatgrass: Increase in cheatgrass root length occurs between mid-December and mid-March, and may reach 36 inches (90 cm) by mid-March [189], with additional growth between mid-March and mid-April. The aerial portion of cheatgrass plants resumes growth after mid-March, with no further increase in height after emergence of inflorescences around mid-May. Prior to April, cheatgrass' root system consists primarily of a single main root with short laterals. About the time the aerial portion of the plants begins regrowth, more lateral development of the root systems may be observed. By the time of spring emergence of associated perennial species, cheatgrass has its root system near fully developed [199]. Therefore, when bluebunch wheatgrass seedlings need moisture to survive the summer, cheatgrass has already depleted moisture beyond the depth of bluebunch wheatgrass roots [186]. Cheatgrass plants with multiple culms tend to develop a more extensive root system than those with only a single culm. Tillering is evident by April [199].

Cheatgrass shoot growth typically occurs in late winter or early spring and continues until soil moisture is exhausted [210,492]. Growth and development is rapid, and plants may flower, develop seeds, and become fully dried within 2 to 3 months [46,207,235,406]. Greenhouse studies indicate a requirement for either vernalization or short day lengths to initiate panicle production in cheatgrass, followed by long day lengths necessary for flowering [154]. As a winter annual, cheatgrass usually flowers in spring, from mid-April through

June [438,492]. The anthers of cheatgrass florets open over about an 11-day period. Seeds reach the dough stage in mid- to late May and are usually ripe in June or July [46,406,438,475]. Cheatgrass seeds shatter within a week after maturity [438]. Plants die and become dry after seeds are ripe, or after early summer drought [46,406,475]. This occurs by June 5 at lower elevations (2,000-4,000 feet (60-1,200 m)) in southwestern Idaho, and by about June 30 in southeastern Idaho, where the season is later because of higher elevation (4,500-6,000 feet (1,370-1,830 m)) [406]. Corresponding stages are about 6 weeks later in bluebunch wheatgrass [186]. In hot weather, cheatgrass roots are unable to supply enough moisture to prevent a drop of leaf water potential, resulting in desiccation and death of the plant [438].

During ripening, cheatgrass plants turn purple and then brown as they mature and senesce. A sudden drop in temperature or a sudden drought causes purple coloration that fades when growing conditions become more favorable [406]. Seeds are viable when the fruits have barely started to turn purple and are still mostly green [207]. Seeds begin to fall shortly after the purple stage is reached [210]. Some viable seed is produced even when the inflorescences are clipped before any purple coloration appears [207]. The characteristic color changes in cheatgrass while it is curing (from green to purple to straw color) are proposed as an indicator of impending flammability because these colors are generally correlated with progressive drying of plants. The onset of purple coloring may be taken as a warning that hazardous fire conditions will develop within 2 weeks [314]. Variations in phenology of about 20 days (emergence of inflorescences, development of purple color, drying, and browning) were observed by Hulbert [207] in plants grown from seed from different geographic locations, and in plants grown under different environmental conditions (location, aspect, elevation).

Cheatgrass may act as a spring annual if fall moisture is inadequate [235]. Some cheatgrass plants that do not produce seed during the spring-summer growing season will overwinter and produce seed the following spring [307]. Observations of a "second crop" of cheatgrass in the late spring have been reported and attributed to the stimulation of growth of new tillers by late spring rains after the cheatgrass had already turned purple [207,210,235].

FIRE ECOLOGY

SPECIES: Bromus tectorum

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations: Cheatgrass establishes from soil-stored and transported seed after fire (e.g. [147,192,207,213,486,488]). It has long been known that cheatgrass is highly adapted to a regime of frequent fires [252,342]. Cheatgrass has a very fine structure, tends to accumulate litter, and dries completely in early summer, thus becoming a highly flammable, often continuous fuel [46,340,406,475,476]. By the time of burning most cheatgrass seeds are already on the ground, and those not near the heat of burning shrubs can survive and allow cheatgrass to pioneer in the newly burned area [46]. Even if fire comes when cheatgrass plants are still green and kills them before they can set seed, there may be enough viable cheatgrass seed in litter and upper layers of soil for plants to reestablish (e.g. [132,189,209,486]).

Cheatgrass is a strong competitor in the postfire environment, where it takes advantage of increased resource availability and produces an abundant seed crop [48,228,484]. A cheatgrass population may average around 1,000 plants per square foot (10,750 per m^2) prior to burning. During a wildfire, most of the cheatgrass seeds beneath the canopy of sagebrush plants are killed by the heat associated with the burning of the shrub. Some cheatgrass seeds located in the interspaces among shrubs are also consumed, while those that are buried or lying in cracks in the soil will likely survive. The next season, surviving seeds germinate and establish at a density of about 1 plant per square foot (11/m^2). These plants are released from competition, and have more water and nutrients available to them. The cheatgrass plants in this sparse population can produce abundant tillers, each supporting many flowers, thus producing a large seed crop [487].

Young and others [487] provide an illustration of cheatgrass fire adaptations with an example from a big sagebrush ecosystem which suggests that hybridization in postfire populations contributes to the success of cheatgrass in these ecosystems. Studies by Novak (e.g. [319,320,322]) and by Pyke and Novak [355] suggest, however, that "the success of cheatgrass throughout many areas in western North America is not due to genetic variation but perhaps due to phenotypic plasticity." See Regeneration Processes for more information.

Fire facilitates cheatgrass dominance on some sites by interrupting successional trajectories of postfire plant communities, and cheatgrass facilitates fire and can thus shorten the interval between fires [48,261,406,455,461,487]. This grass/fire cycle is a serious ecological threat on sites where most native plant species are poorly adapted to fire [69] and is recognized in many ecosystems worldwide [108]. This cycle has been documented in the Great Basin since the 1930s [342,344,461,484], and has been reported in the Mojave and Sonoran deserts beginning in the early 1980s [71]. The result is a type conversion from native shrub and perennial grasslands to annual grasslands adapted to frequent fires.

Fire regimes:

Cheatgrass expansion has dramatically changed fire regimes and plant communities over vast areas of western rangelands by creating an environment where fires are easily ignited, spread rapidly, cover large areas, and occur frequently [484]. An estimated 80,000 km^2 of primarily shrubland and grassland communities in the Great Basin have fire regimes that have been seriously altered because of the presence of cheatgrass. Approximately 67% of this area is in ecosystems that historically experienced mixed-severity fires at intervals of 35 to 100+ years; and about 25% is in areas that historically experienced low-severity fires at intervals of 0 to 35 years [282]. Cheatgrass promotes more frequent fires by increasing the biomass and horizontal continuity of fine fuels that persist during the summer lightning season and by allowing fire to spread across landscapes where fire was previously restricted to isolated patches [37,46,48,71,78,107,240,406,461,475,484]. Fire in these habitats can have severe effects on native species of plants and animals, although the impact of fire regime changes may differ by region and ecosystem type due to differences in the composition and structure of the invaded plant communities [111,329,461,469] and to climatic differences such as occurrence of summer thunderstorms [48,238].

A review by D'Antonio [107] suggests that species that alter the disturbance regime of a site are those that are qualitatively different from the rest of the species in a community (i.e. they have no functional analogues in the invaded system). Where invaders are similar in overall life form to natives, they tend to alter primarily fuel biomass per unit area of ground. This in turn has the potential to influence fire intensity, or slightly modify the existing fire regime, as may be the case with cheatgrass invasion in the more mesic temperate grasslands of North America [173]. Where invaders have no functional analogues (in terms of fuel characteristics) in the invaded system, they have the potential to alter fire frequency and even to introduce fire to ecosystems where it had no evolutionary role, resulting in a complete alteration of that community [107,173]. This has been the case with the introduction of cheatgrass in sagebrush grasslands, desert shrublands, and pinyon-juniper woodlands over extensive areas in the Columbia and Great basins and other areas the Intermountain West. In these systems, cheatgrass fills spaces between widely spaced vegetation and dries earlier than most native species. Thus, from the time plants dry until the onset of fall rains, cheatgrass stands present a fire hazard not usually found in vegetation native to the areas where it is most invasive.

Sagebrush steppe:

Historic fire regimes are variable in big sagebrush/bunchgrass ecosystems, with fire return intervals ranging between 10 and 70 years [19,80,292,332,380,441,485]. The introduction and increasing dominance of cheatgrass has changed the seasonal occurrence and increased the frequency and size of wildfires in these ecosystems, thus altering successional patterns [48,340,365,454,461,476]. The degree of change and impacts on native ecosystems varies with differences in species composition and structure of invaded plant communities [78,390].

Historic fire seasons in the sagebrush steppe occurred between July and September [1,15,237,484], with the middle to end of August being the period of the most extreme fire conditions [79]. Cheatgrass matures by July, while most native herbaceous species it replaces mature in late August. With cheatgrass dominant, wildfires tend to occur earlier in the season, when native perennials are more susceptible to injury by burning [475,476]. Where cheatgrass has invaded the Snake River Plains of Idaho, the natural fire cycle has shortened from 30-100 years to 3-5 years [461]. Fires are larger and more uniform, with fewer patches of unburned vegetation remaining within burns [340,461]. These altered fire regimes and subsequent changes in botanical composition can occur with or without livestock grazing [461].

Wyoming big sagebrush communities are the most xeric of the big sagebrush communities, and the subspecies is more susceptible to fire than the other big sagebrush subspecies [427]. When Wyoming big sagebrush communities burn, resulting vegetation is generally dominated by annuals such as Russian-thistle, tumblemustard, and cheatgrass [427,475]. Fire-tolerant, sprouting shrubs (e.g. rabbitbrush, horsebrush, and ephedra) may persist for awhile, but they cannot tolerate the short fire-free intervals that are common with nonnative annual grass dominance [46,48,340,342,461,473,475]. Continued increases in fire frequency eventually remove and exclude all perennial shrubs, grasses, and forbs from these communities, and cheatgrass competition prevents their reestablishment [340,461,476,484]. Large areas of fire-induced annual communities occur in areas formerly occupied by the Wyoming big sagebrush cover type [290,427].

Basin big sagebrush is also very susceptible to fire. After fires in basin big sagebrush communities, annuals usually dominate, and shrubs such as rabbitbrush and horsebrush may increase. Competition from annuals (cheatgrass and medusahead) makes reestablishment of native grasses difficult [425,427,476,477,484].

Mountain big sagebrush generally has a higher capacity for recovery following disturbance than Wyoming and basin big sagebrush, with a high degree of variability between sites. Cheatgrass increases with grazing in mountain big sagebrush communities, but does not dominate to the extent that it does in drier sagebrush types. Mountain big sagebrush is easily killed by fire, but reestablishes readily from seed and tends to form dense stands after fire [290,426]. Mountain big sagebrush stands may recover within 15 to 20 years after fire, while stands of Wyoming big sagebrush may not be fully recovered after 50 to 75 years [60,77,78]. Work by Miller and Heyerdahl [294] indicates a high degree of spatial variability in historic fire regimes in mountain big sagebrush. In the arid mountain big sagebrush/western needlegrass association, high-severity fires occurred at more than 200-year intervals, while the more mesic mountain big sagebrush/Idaho fescue associations experienced low-severity fires at 10- to 20-year intervals [294].

Salt-desert shrubland:

Fires were historically infrequent in salt-desert shrublands. Desert shrublands usually lack sufficient fine fuels to carry fire, with widely spaced shrubs and bunchgrasses and relatively bare interspaces [69,71,137,453,455]. Historic fire return intervals in these ecosystems (dominated by saltbush, greasewood, creosote, and blackbrush) are thought to average between 35 and 100 years or more [332]. Most native plant species in the deserts of North America are poorly adapted to survive fire ([48,69] and references therein).

While cheatgrass had established in some of these areas earlier this century [254,453,457,496], West [455] suggests that it did not dominate until the wet years of 1983-1985. Landscapes dominated by alien annual grasses, especially annual bromes (*Bromus*
spp.) are more flammable than those dominated by native forbs in the Mojave Desert. Brooks [69] suggests several possible reasons for this, including: a higher surface-to-volume ratio of grasses compared to forbs; more continuous vegetative cover; and the ability of alien annual grasses to remain rooted and upright longer than native forbs, allowing them to persist as flammable fuels into the summer, when the threat of fire is highest [69]. Thick layers of annual plant litter accumulate quickly and decompose very slowly in desert regions [69,487]. Following 2 or more years with above-average precipitation, sufficient fuel may be present to sustain

a wildfire [238] and convert the plant community to cheatgrass (or other nonnative annual grasses) indefinitely [339]. In experimental fires in the Mojave Desert, accumulations of litter led to particularly hot temperatures, long flame residence times, and continuous burn patterns [69].

Postfire plant communities in the Mojave and Sonoran deserts are typically dominated by nonnative annual grasses ([69] and references therein), so burned areas are likely to be more susceptible to fire than unburned areas. Brooks and Pyke [71] note that fire regimes in the Mojave and Sonoran deserts are beginning to shift toward short-return intervals. Repeated fires stress and kill native perennials. Eventually wind and water erosion may occur, removing and diluting soil organic matter and attendant nutrient concentrations and safe sites around shrubs. After fire has eliminated native perennials, essential mycorrhizae may also be eliminated [464]. Biological soil crusts are also killed by severe fire, and the unusually large, frequent fires associated with cheatgrass dominance can preclude crust species recolonization and succession [41]. West [455] gives some specific examples of fire effects on salt desert shrub ecosystems in Utah and Nevada.

Pinyon-juniper:

Pinyon-juniper woodlands are characterized by a large number of diverse habitat types that vary in tree and herbaceous species composition and density, and fire regime characteristics. Fire severity and frequency vary, depending largely on site productivity. On less productive sites with discontinuous grass cover, fires were probably infrequent, small, and patchy [332]. Fire intervals were probably greater than 100 years in these areas, but did occur more frequently under extreme conditions [172]. On more productive sites where grass cover was more continuous, fire intervals may have been 10 years or less, maintaining more open stands. Historical fire regimes in dense stands were a mixture of surface and crown fires, with surface fires at intervals of 10-50 years and crown fires at intervals of 200-300 years or longer. Fire susceptibility in pinyon-juniper communities also depends on the stage of stand development. In young open stands, shrubs and herbaceous cover may be sufficient to carry fire, but as the stand approaches crown closure, herbaceous cover declines and eventually becomes too sparse to carry fire [332].

A dramatic increase in fire size and frequency has been observed in pinyon-juniper woodlands as cover of nonnative annuals such as cheatgrass increases [289,482]. Where fires have burned in singleleaf pinyon-Utah juniper woodland invaded by cheatgrass in Nevada, the woodland is being replaced by great expanses of annual grassland dominated by cheatgrass [48]. Cooler and more mesic woodlands seem to be less susceptible to invasion and complete dominance by introduced annuals; however, more information is needed regarding factors that influence pinyon-juniper woodlands susceptibility to invasion [289].

Prolonged livestock grazing and fire suppression have contributed to a decline of perennial grasses and an increase in shrubs and trees at many pinyon-juniper sites [251,329]. A subsequent increase in the number of large, high-severity fires due to invasion by nonnative annuals such as cheatgrass has resulted in a loss of these shrubs and trees [329]. When cheatgrass is present in the understory with little or no perennial vegetation, removing pinyon and juniper trees usually leads to cheatgrass dominance [348].

Many dry temperate conifer forests

have become susceptible to severe wildfires because of the dense forest structure that results from a century of fire exclusion and past management practices (e.g. [20]). Fires in these ecosystems, especially fires of high severity, can lead to invasion and dominance of cheatgrass. At Sequoia-Kings Canyon National Park, prescribed burning in ponderosa pine in the Cedar Grove section appears to have promoted vigorous invasion of cheatgrass [228]. Cheatgrass had higher cover on severely burned sites, compared to less severely burned sites, in ponderosa pine in Arizona [105]. The presence of cheatgrass-dominated ecosystems adjacent to these dense forests is also likely to cause larger, more frequent, and more severe wildfires [191]. Cheatgrass fueled a large wildfire in the ponderosa pine forest type in Oregon as early as 1938 [450]. Fire effects on many species, and the effects of invasives on disturbance regimes in temperate and boreal forests, are still poorly understood [191].

In temperate grasslands

of North America, fire has historically been an important selective force, and native communities are well adapted to frequent fires in most cases. Cheatgrass is more commonly found in the northern portion of these temperate grasslands. In more arid habitats with low natural fire frequencies cheatgrass is able to replace native species. In mesic grasslands, however, cheatgrass does not compete as successfully against native perennial grasses, and it does not appear to pose as great a threat to native communities. The effects of new species that create greater fuel loads and/or increase the probability of fire or the rate of fire spread are expected to have less dramatic effects in these communities [173].

A review by Grace and others [173] suggests that cheatgrass is favored by occasional burning at study sites within shortgrass steppe and mixed-grass prairies. Smith and Knapp [392] provide evidence that cheatgrass and other nonnative species are less frequent on tallgrass prairie sites at Konza Prairie, Kansas, that are annually burned than they are on unburned sites. Across the broad range of conditions and circumstances that occur in temperate grasslands, a complex interplay of contemporary and historical factors will ultimately determine how fire interrelates with invasive species [173].

Cheatgrass fire regime:

Cheatgrass often dominates postfire plant communities, and once established, cheatgrass-dominated grasslands greatly increase the potential and recurrence of wildfires. Cheatgrass fires tend to burn fast and cover large areas, with a fire season from 1 to 3 months longer than that of native rangeland [332,370]. The average fire-return interval for cheatgrass-dominated stands is less than 10 years [332], and is about 3 to 6 years on the Snake River Plain as reported by Whisenant [461] and Peters and Bunting [340]. This adaptation to and promotion of frequent fires is what gives cheatgrass its greatest competitive advantage in ecosystems that evolved with less frequent fires. The cheatgrass-fire cycle is self-promoting, as it reduces the ability of many perennial grasses and shrubs to re-establish and furthers the dominance of cheatgrass [335,340]. Moisture availability can affect cheatgrass productivity and thus affect fuel loads on a site. Drought years may reduce the dominance of cheatgrass in both recently burned and unburned areas, thus decreasing fuel loads and the chance of fire [238].

The following table provides some fire regime intervals for ecosystems in which cheatgrass may occur. For further information, see the FEIS summary on the dominant species listed below.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
grand fir	*Abies grandis*	35-200 [18]
California chaparral	*Adenostoma* and/or *Arctostaphylos* spp.	< 35 to < 100 [332]
bluestem prairie	*Andropogon gerardii* var. *gerardii-Schizachyrium scoparium*	< 10 [247,332]
Nebraska sandhills prairie	*A. g.* var. *paucipilus-S. scoparium*	< 10
bluestem-Sacahuista prairie	*A. littoralis-Spartina spartinae*	< 10 [332]
silver sagebrush steppe	*Artemisia cana*	5-45 [194,357,468]
sagebrush steppe	*A. tridentata/Pseudoroegneria spicata*	20-70 [332]
basin big sagebrush	*A. t.* var. *tridentata*	12-43 [380]
mountain big sagebrush	*A. t.* var. *vaseyana*	15-40 [19,80,292]
Wyoming big sagebrush	*A. t.* var. *wyomingensis*	10-70 (40**) [441,485]
coastal sagebrush	*A. californica*	< 35 to < 100
saltbush-greasewood	*Atriplex confertifolia-Sarcobatus vermiculatus*	< 35 to < 100

desert grasslands	*Bouteloua eriopoda* and/or *Pleuraphis mutica*	5-100
plains grasslands	*Bouteloua* spp.	< 35
blue grama-needle-and-thread grass-western wheatgrass	*B. gracilis-Hesperostipa comata-Pascopyrum smithii*	< 35
blue grama-buffalo grass	*B. gracilis-Buchloe dactyloides*	< 35
grama-galleta steppe	*B. gracilis-Pleuraphis jamesii*	< 35 to < 100
blue grama-tobosa prairie	*B. gracilis-P. mutica*	< 35 to < 100 [332]
cheatgrass	*Bromus tectorum*	< 10 [340,461]
California montane chaparral	*Ceanothus* and/or *Arctostaphylos* spp.	50-100 [332]
curlleaf mountain-mahogany*	*Cercocarpus ledifolius*	13-1000 [22,384]
mountain-mahogany-Gambel oak scrub	*C. ledifolius-Quercus gambelii*	< 35 to < 100
blackbrush	*Coleogyne ramosissima*	< 35 to < 100
Arizona cypress	*Cupressus arizonica*	< 35 to 200
northern cordgrass prairie	*Distichlis spicata-Spartina* spp.	1-3
California steppe	*Festuca-Danthonia* spp.	< 35
juniper-oak savanna	*Juniperus ashei-Quercus virginiana*	< 35
Ashe juniper	*J. ashei*	< 35
western juniper	*J. occidentalis*	20-70
Rocky Mountain juniper	*J. scopulorum*	< 35 [332]
western larch	*Larix occidentalis*	25-100 [18]
creosotebush	*Larrea tridentata*	< 35 to < 100
Ceniza shrub	*L. tridentata-Leucophyllum frutescens-Prosopis glandulosa*	< 35
wheatgrass plains grasslands	*Pascopyrum smithii*	< 35
pinyon-juniper	*Pinus-Juniperus* spp.	< 35 [332]
Mexican pinyon	*P. cembroides*	20-70 [297,411]
Rocky Mountain lodgepole pine*	*P. contorta* var. *latifolia*	25-300+ [16,18,376]
Sierra lodgepole pine*	*P. c.* var. *murrayana*	35-200 [18]
Colorado pinyon	*P. edulis*	10-400+ [155,172,229,332]
Jeffrey pine	*P. jeffreyi*	5-30
western white pine*	*P. monticola*	50-200
Pacific ponderosa pine*	*P. ponderosa* var. *ponderosa*	1-47 [18]
interior ponderosa pine*	*P. p.* var. *scopulorum*	2-30 [18,28,250]
Arizona pine	*P. p.* var. *arizonica*	2-15 [28,101,385]
galleta-threeawn shrubsteppe	*Pleuraphis jamesii-Aristida purpurea*	< 35 to < 100 [332]
quaking aspen (west of the Great Plains)	*Populus tremuloides*	7-120 [18,177,279]

mesquite	*Prosopis glandulosa*	< 35 to < 100 [278,332]
mesquite-buffalo grass	*P. glandulosa-Buchloe dactyloides*	< 35
Texas savanna	*P. glandulosa* var. *glandulosa*	< 10 [332]
mountain grasslands	*Pseudoroegneria spicata*	3-40 (10**) [16,18]
Rocky Mountain Douglas-fir*	*Pseudotsuga menziesii* var. *glauca*	25-100 [18,19,21]
California mixed evergreen	*P. m.* var. *m.-Lithocarpus densiflorus-Arbutus menziesii*	< 35
California oakwoods	*Quercus* spp.	< 35 [18]
oak-juniper woodland (Southwest)	*Quercus-Juniperus* spp.	< 35 to < 200 [332]
coast live oak	*Q. agrifolia*	<35 to 200
canyon live oak	*Q. chrysolepis*	<35 to 200
blue oak-foothills pine	*Q. douglasii-Pinus sabiniana*	<35
Oregon white oak	*Q. garryana*	< 35 [18]
California black oak	*Q. kelloggii*	5-30 [332]
oak savanna	*Q. macrocarpa/Andropogon gerardii-Schizachyrium scoparium*	2-14 [332,445]
interior live oak	*Q. wislizenii*	< 35 [18]
blackland prairie	*S. scoparium-Nassella leucotricha*	< 10
little bluestem-grama prairie	*S. scoparium-Bouteloua* spp.	< 35 [332]
western redcedar-western hemlock	*Thuja plicata-Tsuga heterophylla*	> 200 [18]
elm-ash-cottonwood	*Ulmus-Fraxinus-Populus* spp.	< 35 to 200 [128,445]

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

POSTFIRE REGENERATION STRATEGY [407]:
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: Bromus tectorum

- 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:
Live cheatgrass plants are susceptible to heat kill, as with a flame thrower or handled propane torch, though they are difficult to burn when green. When cheatgrass plants are dry enough to burn, they are already dead, and

have already set seed. Fire will then reduce cheatgrass plants to ash.

Cheatgrass seeds are also susceptible to heat kill, but can survive fires of low-severity if the entire litter layer is not consumed or if seeds are buried deeply enough to be insulated from the heat [476]. The amount of litter or ash left on a site is a good indicator of the amount of cheatgrass seed surviving on that site [489]. Low density of cheatgrass immediately following fire [484] indicates either low numbers of cheatgrass seed in the seed bank, or poor survival of seeds during fire [229].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
The effects of fire on cheatgrass plants and seeds vary with timing and severity of fire and the composition and density of the prefire plant community.

If fire occurs when seed remains in panicles above ground, most seeds will be killed and cheatgrass density will decline immediately following fire [70,71,354]. The chances of seed surviving fire are enhanced once they have dispersed onto or beneath the soil surface [70,110]. In sagebrush communities, most of the litter and cheatgrass seeds are found under the canopies of sagebrush plants [483]. The woody biomass of the shrub, plus litter accumulations, provide sufficient fuel to elevate temperatures high enough for a long enough period to consume cheatgrass seeds on these microsites. Some cheatgrass seeds in the interspace zones are also consumed by fire, but many survive even though the cheatgrass herbage is completely consumed [476]. Fire from herbaceous fuel alone is not usually hot enough to consume cheatgrass seeds [147]. Although fires in pure cheatgrass stands, without woody fuel, are less severe, cheatgrass seed banks can be substantially reduced after fire [489]. For example, after a fire in a community dominated by cheatgrass, tumblemustard, and Russian-thistle in Utah, postfire density of cheatgrass seeds in the seed bank was <3% of that on unburned plots. Densities of cheatgrass seeds were higher on a low-severity burn compared with a high-severity burn. Nonetheless, the seed bank recovered to preburn levels after l growing season, even on the more severely burned site [213].

PLANT RESPONSE TO FIRE:
Cheatgrass establishes from soil-stored and transported seed after fire (e.g. [147,192,207,213,486,488]). On preferred sites where cheatgrass thrives in the Intermountain West, cheatgrass can establish or maintain dominance in the postfire environment (e.g. [91,98,271]), sometimes maintaining dominance for decades (e.g. [48]), even after artificial seeding with competitive plants (e.g. [45,169,329]).

Cheatgrass may also invade recently burned sites where it does not usually dominate or did not previously occur (e.g. [105,216,228,259]) if there is an available seed source. For example, pinyon-juniper woodlands with large, continuous tree canopies limit herbaceous understory and facilitate severe summer fires that promote invasion of nonnative species such as cheatgrass and red brome [458]. Koniak and Everett [245] observed that most of the seed bank in a mature singleleaf pinyon stand in California consisted of annuals, many of which were not present in the community as mature plants. Fire can promote germination of these dormant seeds by consuming litter containing allelopathic compounds [329], and/or altering the nutrient, water, microbial, temperature, and light regimes of the seedbed [61,62,64,244,329].

There are some examples in the literature reporting decreased density of cheatgrass in the 1st postfire year (e.g. [5,350,462]). Others report increased cover of cheatgrass the 1st postfire year in ponderosa pine [17,283], sagebrush [5], shadscale [176], bluebunch wheatgrass [217,409], and cheatgrass communities [89]. These studies provide no additional information on plant community changes in subsequent years.

More common are reports that cheatgrass density decreases the 1st postfire year and approximately equals preburn density by the 2nd or 3rd postfire year in sagebrush [110,111,210,333,380,484], desert shrub [83], cheatgrass [114], and antelope bitterbrush/cheatgrass communities [79]. This is because many cheatgrass seeds are killed by fire [192,213,380]: A majority of cheatgrass seeds are found under shrub canopies which tend to be the microsites that experience the greatest fire severity [192,489]. In a northern Nevada study, fire reduced cheatgrass seed density approximately 96% to 99%, from 5,000 to 8,000 seeds per square meter to 20 to 300 seeds per square meter [489]. Thus the number and density of cheatgrass plants are reduced the 1st postfire year. These plants, however, respond to the released environmental potential resulting from the reduction in plant density and increased water and nutrient availability, and can become large plants with many tillers and high seed production [70,111,212,283,484].

Young and Evans [484] recorded 10 cheatgrass plants per square meter 1 year after fire, and 10,000 plants per square meter 3 years after fire. On an unburned control plot, the maximum number of seeds on a cheatgrass plant was 250. On burned plots, the lowest seed production per plant 1 year after fire was 960 [484]. While plant and seed bank density may decrease the 1st postfire year, biomass and seed production may equal or exceed that of the prefire population, resulting in increased plant and seed bank density by the 2nd or 3rd postfire year [192,213,329,476,484]. The increase to peak population density of cheatgrass after fire may require several years on some sites [229]. These increases in cheatgrass plant and seed bank density can prevent the establishment of natives and predispose the vegetation to recurring wildfires [484].

A few studies found that cheatgrass increased in the early postfire years and then decreased over time. These include a wildfire in a northeastern California antelope bitterbrush/bottlebrush squirreltail community [102]; fires on sites dominated by some combination of mountain big sagebrush, antelope bitterbrush, Saskatoon serviceberry (*Amelanchier alnifolia*), Wyoming big sagebrush, and true mountain-mahogany (*Cercocarpus montanus*) in south-central Wyoming [100]; and a wildfire under ponderosa pine in Idaho [283]. A study of several burns in Utah juniper-singleleaf pinyon communities in west-central Utah found that cheatgrass cover varied from 12.6% in a 3-year-old burn to 0.9% in the oldest stands (85-90 years without fire). On these sites, cheatgrass was one of the initial dominant annuals, reaching maximum density in the first 3 to 4 years [31]. Cheatgrass declined in cover the first 22 years after fire, then leveled off and stayed about the same for the remainder of the invasion sequence [32]. Similarly, in California chamise (*Adenostoma fasciculatum*) chaparral sites, cheatgrass was most abundant 3 to 5 years after fire, and its abundance tapered off as brush cover closed. Prior to burning, cheatgrass and other annual grasses were found only along trails, firebreaks, and openings [205].

Examples where fire seems to have had little or no effect on cheatgrass populations include several sagebrush/bunchgrass sites in the northern Great Basin, where cheatgrass populations were unchanged by prescribed fire treatments over 3 years of the study [81]. In a mountain meadow bordering Jeffrey pine in the Sierra Nevada, cheatgrass was present in both burned and unburned dry meadow plots but showed no apparent response to prescribed fires [68]. In a mountain big sagebrush-antelope bitterbrush community with a healthy understory of perennial bunchgrasses in Oregon that was subjected to fall and spring prescribed fire, there was no increase of cheatgrass after fire. Perennial bunchgrasses increased to >50% of total vegetation cover 1 to 2 years after the fire [356].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Cheatgrass response to fire depends on plant community and seed bank composition, density, and spatial distribution; season of burning; fire severity, frequency and patchiness; scale of consideration; postfire management; and climatic conditions. Generalizations are difficult because each combination of climate, vegetation, and soil must be considered separately [78,224,311], as well as considerations of environmental differences both at the time of burning and during subsequent plant reestablishment [413].

Timing of fire:

If burned during a crucial time during seed ripening, fire can greatly reduce the density of the succeeding cheatgrass stand [311]; however, postfire seed production may equal or exceed that of the prefire population, resulting in increased density the following year [192,213,329,476,484]. Timing of fire is important also because of variable damage to potential competitors in the native community. For example, cool-season perennial grasses such as bluebunch wheatgrass and western wheatgrass may be less damaged by late-summer wildfires than by fires earlier in the growing season [329].

Fire size and frequency:

Nonnative, invasive grasses generally benefit from fire and promote recurrent fire. Fire kills biologic soil crusts

[41,215,328], thereby allowing more germination sites for cheatgrass for several years or even decades, as crusts are slow to recover [41,83]. Recurrent fires also tend to enhance cheatgrass dominance because native species cannot usually persist under a regime of frequent fires. Native plant assemblages are thus converted to nonnative annual grasslands. Frequency and size of fires is then further increased [71,334,492].

Explanations of why individual cheatgrass plants thrive in the postfire environment have been explored, but remain unclear. Blank and Young [66] found that after exposing cheatgrass seeds to smoke of burning big sagebrush, the rates of new leaf production and leaf elongation in cheatgrass seedlings were significantly ($p<0.05$) greater than cheatgrass seedlings from untreated seed. Blank and others [65] also found that cheatgrass had significantly ($p<0.05$) greater aboveground mass when grown in post-wildfire soil than plants grown in unburned soil. Individual cheatgrass plants may thrive in the postfire environment due to temporary increases in the availability of soil nutrients, especially inorganic nitrogen, after fire. Soil disturbance and fire are known to accelerate mineralization of nitrogen [63,103,104,400,408]. Cheatgrass displays flexibility in effectively using both patches of nitrogen and early pulses of nitrogen which may contribute to its effectiveness in competing with perennials [129]. It has been suggested that changes in nitrogen availability, and in the abundance of NO_3^- relative to NH_4^+, play important roles in allowing cheatgrass stands to persist in much of the western United States [400,479]. Studies by Blank and others [61,63,65] further explore changes in soil chemistry after fire under sagebrush and cheatgrass. These differential changes may help to explain postfire succession of cheatgrass in different microsites.

Microsite effects:

Cheatgrass' postfire response varies between microsites and appears to be related to microsite fuel gradients and subsequent differences in fire severity between microsites. Following wildfires in sagebrush steppe, cheatgrass 1st dominated the interspaces between shrubs, and later occupied shrub subcanopy microsites [484,489]. A similar postfire successional pattern was observed in big sagebrush and Colorado pinyon-Utah juniper communities in west-central Utah [329]. Cheatgrass became dominant in the interspaces between burned trees by the 2nd postfire year. In the subcanopy zones of burned trees, cheatgrass did not become dominant until the 3rd year following fire, and was preceded by exotic annual forbs. In creosotebush scrub vegetation in the Mojave Desert, annual brome (red brome, cheatgrass, and Chilean chess (*Bromus berterianus*)) prefire biomass was 3 times higher under the shrub canopy than in drip line microsites. Following experimental fires, annual bromes had poor recovery the 1st four postfire years [70]. The observed patterns are probably due to higher temperatures and longer duration of heat exposure under canopies (i.e. higher-severity fire), where prefire fuel loads tend to be higher. The result is greater consumption of litter and seeds in subcanopy zones, leaving an unfavorable and unlikely site for cheatgrass germination [70,329]. Results presented by Blank and others [61,64] suggest that because of cooler, briefer fires in cheatgrass microsites compared with sagebrush microsites, postfire soil qualities differ in concentrations of organic and inorganic anions, which, in turn, may influence seed germination, plant establishment, and mineral nutrition (i.e. postfire succession). In some cases, recolonization by cheatgrass after fire may be delayed by drought or in areas where interspace cheatgrass densities are low and seeds must disperse from adjacent unburned areas [70]. Additional research is needed to understand how these changes affect postfire succession in specific plant communities.

Effects of fire severity on postfire dominance of cheatgrass at the site scale were observed in ponderosa pine forests in Arizona that burned in early summer. Two years after fire, cheatgrass had <0.5% cover in unburned sites, ~19% cover in high-severity burn sites, and ~3% in moderate-severity sites [105].

Plant community effects:

The exact nature of secondary succession following fire in sagebrush/bunchgrass ecosystems is not clearly understood due to the highly variable response of subspecific populations of big sagebrush [78,224]. Mountain big sagebrush is the most mesic of the big sagebrush subspecies, usually occurs at the highest elevations, is probably the best adapted to fire, and tends to have the most productive herbaceous component of the big sagebrush communities. It is well adapted to postfire establishment via seeds that are stimulated to germinate by light and heat. It also grows rapidly and reaches reproductive maturity within 3 to 5 years, and populations may return to preburn levels within 15 to 20 years, or 30 years after a severe fire [78]. Young and Evans [484] described big sagebrush communities at higher elevations, under more mesic conditions, and/or long distances from livestock water, as those where cheatgrass was still absent in 1978. Mountain big sagebrush is probably the most likely to resist invasion by cheatgrass, but cheatgrass may initially dominate the postfire community, especially if postfire cover of perennial grasses is low [33]. Similarly, cheatgrass is often found with threetip sagebrush, but seldom becomes a problem following fire or other types of disturbance [78].

Another subspecies of big sagebrush with limited distribution, xeric big sagebrush (*Artemisia tridentata* ssp. *xericensis*), sometimes referred to as an ecotype of mountain big sagebrush, is found primarily in western Idaho and eastern Oregon and is restricted to a zone where the annual precipitation exceeds 12 inches (300 mm), elevation is less than 4,500 feet (1360 m), and the summers are relatively warm. Many of these communities are on relatively steep slopes, have a high potential for human and lightning-caused fires, and burn frequently. These frequently burned areas are often dominated by cheatgrass and medusahead [78]. Similarly, at Craters of the Moon National Monument, Idaho, cheatgrass is most likely to occur in mountain big sagebrush communities on xeric sites, such as those growing at lower elevations or on cinder-derived soils, where mountain big sagebrush is less competitive [33].

The majority of the historic area of basin big sagebrush is now under intensive agricultural cultivation, so these communities are now restricted primarily to field edges, swales, and along water drainage ways in areas dominated by other sagebrush species. Sites formerly dominated by basin big sagebrush are susceptible to invasion by cheatgrass, and as such, vast areas of this type have been converted to annual grasslands. Basin big sagebrush does not sprout, and repeated fires have eliminated it from many of the remaining sites [78,102]. In eastern Oregon, basin big sagebrush was completely eliminated by fall burning, while spring burning resulted in an 84% decrease in density. Burning in both seasons reduced cheatgrass density at postfire year 1 compared to prefire density [380].

Wyoming big sagebrush is the most arid of the big sagebrush types, occurring on sites with annual precipitation of less than 7 inches (178 mm) in some places. Wyoming big sagebrush and its associated perennial grasses are not well adapted to fire, as they evolved in low-productivity communities with few herbaceous species and infrequent fires. Wyoming big sagebrush establishes readily from seed after fire, but repeated fires rapidly diminish the on-site seed source and reduce opportunities for establishment. Cheatgrass predominates in early successional stands of the Wyoming big sagebrush series in western Idaho, northern Nevada, and Oregon, thus increasing the likelihood of fire and subsequent dominance of cheatgrass. Once a site is dominated by cheatgrass, the risk of wildfire increases and the possibility of succession to perennial grasses or shrubs by natural regeneration greatly decreases. Many Wyoming big sagebrush sites have been burned repeatedly by wildfire, resulting in a conversion to nearly pure stands of cheatgrass [78].

Cheatgrass dominance may be avoided on sites that have sufficient cover of native perennials, proper management of livestock, and favorable climatic conditions for postfire recovery [32]. Three years after a severe wildfire on an ungrazed foothill mountain grassland in western Montana, cheatgrass cover was lower in burned patches than in unburned patches, and cheatgrass showed no indication of invading the burn. At that time Idaho fescue and bluebunch wheatgrass cover were similar to unburned levels, and rough fescue cover was slightly below unburned levels [15]. After a mid-summer, lightening-caused wildfire on a good condition sagebrush-grass site (Wyoming big sagebrush, black sagebrush, and bluebunch wheatgrass) in central Utah, cheatgrass dominated the site the 1st postfire year. Livestock were kept off the site, and with favorable precipitation, perennial bunchgrasses returned to nearly their preburn cover the 2nd year. Although cheatgrass had highest cover of grasses, the authors conclude that sagebrush-grass sites in good condition may be improved for cattle production with a few years of livestock exclusion following wildfire [456]. On a similar site, perennial grasses came to dominate plant cover over time, especially in ungrazed plots. Cheatgrass became locally almost absent during a 3-year intense drought, so the threshold to an annual-dominated site was not crossed [459]. Similarly, a mesic site dominated by Colorado pinyon, Gambel oak, true mountain-mahogany, and mountain snowberry (*Symphoricarpos oreophilus*) was seeded with nonnative grasses, including crested wheatgrass and smooth brome (*Bromus inermis*), after fire. Seeded sites had lower cover of cheatgrass than drier sites that were not seeded [329]. A tallgrass prairie community in Oklahoma was burned under prescription in mid-April for 3 consecutive years. At postfire year 3, cheatgrass cover was significantly ($p<0.05$) lower on burned sites than on unburned sites, both with and without grazing [95].

The following Research Project Summaries provide information on prescribed fire use and postfire response of plant community species including cheatgrass:

- Nonnative annual grass fuels and fire in California's Mojave Desert
- Vegetation response to restoration treatments in ponderosa pine-Douglas-fir forests of western Montana

FIRE MANAGEMENT CONSIDERATIONS:
As a management tool, fire can be used to either kill unwanted species or to simulate historic fire regimes and promote desired species. Historic fire regimes did not occur in the presence of many invasive plants that are currently widespread, and the use of fire may not be a feasible or appropriate management action if fire-tolerant invasive plants are present. For example, while fire may be an important natural component of the Great Basin ecosystem, its reintroduction by land mangers is complicated by the presence of invasive plants such as cheatgrass [71]. Fire management should be conducted in ways that prevent establishment of invasive species [191], and the management of fire and invasive plants must be closely integrated for each to be managed effectively [71].

Rasmussen [362] presents considerations (e.g. species composition, fuel load, fuel continuity, and weather) to be addressed when using prescribed fire in sagebrush steppes, and general prescriptions that could be used. When precipitation is below 12 inches (300 mm), caution should be used to ensure desired plant response. If the objective is to maintain the perennial herbaceous vegetation, prescribed burning is most effective when used before sagebrush dominates the site and effectively excludes perennial herbaceous plants. Such timing reduces the need for seeding following a burn. If the objective is to maintain the sagebrush, prescribed burning has very limited applicability [362].

Fire as a control agent for cheatgrass:

In sagebrush ecosystems, prescribed burning alone will generally decrease cheatgrass cover only in the short term, so in areas where cheatgrass dominates the understory, fire may best be used as a seedbed preparation technique prior to seeding desirable species [139,147,362,406]. Burning of mixed shrub-cheatgrass stands generates enough heat to kill most cheatgrass seeds and may offer a 1-season window for the establishment of perennial seedlings [144,484,492]. The abundance of viable seeds of cheatgrass after a burn can be judged by examining seeds in the ash. Even if the lemma and palea are charred, if entire caryopses can be identified some seed will be viable and germinate [489].

The period of reduction of cheatgrass density (1-2 years) is not usually long enough to allow for the establishment of perennial seedlings [77]. Cheatgrass plants that do establish the 1st postfire year tend to produce so much seed per plant that total postfire cheatgrass seed production for a site may actually increase by a factor of 100 over preburn production [307,474]. Unless desirable species establish and outcompete cheatgrass, density of cheatgrass plants may exceed preburn levels within 1 to 5 years [307,469]. On range sites in Washington, seeded grasses were successfully established on sites where cheatgrass density was reduced to less than 90 seedlings/m^2 with summer burning and to less than 40/m^2 with burning combined with fall spraying of herbicide [180].

If fire is used as a pretreatment to seeding in sagebrush communities depleted of perennial herbs, and levels of annual grasses are low at the time of the fire, perennial seedlings may establish before the annuals dominate the site if perennials are seeded the 1st year after fire [77]. Seeding burned areas immediately after fire is likely to reduce the "influence" of cheatgrass but is not likely to exclude it. A closed-canopy Colorado pinyon-Utah juniper site in the Green River corridor in Utah burned in 1976. Response of native plants was low (because of sparse seed bank), and within a decade cheatgrass and musk thistle (*Carduus nutans*) dominated the site. The site was then burned under prescription in late June 1990, when cheatgrass seed was mature but not yet shattered. The site was aerially seeded in fall 1990 with aggressive, introduced grasses including crested wheatgrass, intermediate wheatgrass (*Thinopyrum intermedium*), orchardgrass (*Dactylis glomerata*), and smooth brome (*Bromus inermis*). Some of the burned area was not seeded, and cheatgrass established in unseeded areas. There were fewer and smaller cheatgrass plants in the seeded area [169]. However, cover of cheatgrass was slightly higher in seeded versus unseeded plots following an August wildfire in sagebrush steppe in Idaho [363].

Late spring or early summer burns, before cheatgrass seed matures, may effectively control cheatgrass [25,311,362]; however, burning before the seed is ripe is difficult because the plants are still green [25]. This timing is also a period of high sensitivity to fire damage for cool-season perennial grasses. In areas where native warm-season grasses are desired, a prescribed fire that kills cheatgrass seedlings and reduces the surface seed bank may be effective [492]. A site in Oregon that was dominated by cheatgrass and annual forbs was burned under prescription in July. The density of cheatgrass decreased and bottlebrush squirreltail increased in burned areas [494]. Prescribed burning prior to herbicide application may increase the effectiveness and/or reduce the application rate required for effective control of cheatgrass [387]. Preliminary results from a site in Oregon indicate that glyphosate treatment or mowing 1 year following summer prescribed burning were equally effective at reducing medusahead and cheatgrass cover [349].

In all cases where invasive species are targeted for control, the potential for other invasive species to fill their void must be considered [71,187,371].

Fire as a control agent for shrubs and trees: Prescribed burning to reduce cover of shrubs and trees has been practiced for decades (e.g. [25,58,60,102,289,334]), and was sometimes successful at enhancing desirable species without increases in cheatgrass [58,102]. The resulting plant community is dependent on several variables, however, including the composition of the plant community and seed bank before burning, the conditions of the fire, postfire management, and climatic conditions.

The cheatgrass problem on rangeland dominated by sagebrush was probably exacerbated by efforts, beginning in the 1930s, to control sagebrush and increase grazing capacity. A report by Pechanec and others [334] recommends against burning range with little understory of perennial grasses unless it is to be reseeded the 1st fall following the burn. They note that where cheatgrass is present, burning the range is likely to increase cheatgrass and damage desirable perennial species. Proper grazing management following burning is essential in maintaining desirable species.

Blaisdell and others [60] suggest that each situation be carefully examined and evaluated before burning can be prescribed as a plant control measure, and emphasize that areas with a poor stand of desirable perennials prior to burning will probably require postfire seeding to provide satisfactory forage production and delay return of sagebrush or other unwanted species such as cheatgrass, halogeton, and medusahead [60]. Burning in Wyoming big sagebrush will remove brush, but it will not provide more perennial grass where cheatgrass has become dominant [78]. Bunting and others [78] suggest prescribed burning in areas with 10 to 15% cover of sagebrush and desirable plants present "in a density that will allow a favorable postfire response." Young and Evans [483,484] determined that 2 perennial grass plants per square foot is the minimum necessary to preempt invasion by nonnative annual species and/or shrub seedlings.

A review by Bunting [77] suggests many sites are difficult to burn because herbaceous productivity is inherently low. Sites with less than 600 kg/ha of fine fuels will be difficult to burn. Even if sites with low amounts of herbaceous plant cover are burned, it may take many years for the desirable perennials to establish, which leaves the site open to erosion and invasion by nonnative plants. If the fine fuel load is sufficient but it is composed of annuals, establishment of perennials may still be prevented, and fire return intervals may decrease. Thus, the site may be dominated by annuals indefinitely. Then the management concern is for fire prevention as a means to increase the fire-free interval until desirable perennial vegetation can become established [77].

Postfire colonization potential: Cheatgrass can invade recently burned sites from offsite seed sources [17,156,157,365], or may establish from seeds in the soil seed bank (e.g. [139]), even if plants are absent from the site at the time of the fire (e.g. [245]). Predicting a site's susceptibility to invasion may be difficult. Management techniques to help reduce postfire cheatgrass invasion may include elimination of nonnative seed sources from roadsides and other disturbance areas adjacent to burn sites, and increasing size of burns to increase the distance from seed sources. Increasing size of burns does, however, also increase distance from native seed sources [228].

Excessive or poorly timed grazing after burning can also increase cheatgrass dominance [334]. The optimum amount of grazing rest and deferment that is needed following fire in sagebrush steppe and pinyon-juniper vegetation continues to be controversial, but varies with vegetal composition, site potential, objectives of the burn, and environmental conditions following fire [77]. It has been suggested that grazing be deferred on seeded lands for a minimum of 2 years with nonnative seeding, and a minimum of 5 to 8 years with native seedings [144,239,487].

Cheatgrass fires:

The majority of grassland fires in the Intermountain West are small (<10 acres (4 ha)) and represent <1% of total acreage burned. Large fires (>5,020 acres (2,008 ha)) are infrequent, but represent >70% of the acreage burned [238]. These fires are of particular concern for rehabilitation efforts [371], and predicting their occurrence and behavior would be beneficial to land managers in assigning resource allocation prior to the fire season [238]. Knapp [237,238] suggests that these large fires have distinct spatial patterns, and their occurrence can be predicted based on antecedent moisture conditions. Summer moisture conditions in the year preceding that of large fire years tend to be near-normal or wetter. Conversely, <20% of all the large fires occur when the previous summer's moisture conditions were below normal [237,238]. Other researchers have suggested this relationship between precipitation in the preceding winter months and large fires during the following summers [48,487]. Moisture conditions in the summer in which the large fires occur appear to have less influence on the likelihood of those fires, suggesting that fuel moisture conditions are secondary to fine-fuel amounts for promoting large fires on rangelands [237,238].

Knapp [238] examined the spatial and temporal occurrence of large grassland fires in the Intermountain West for the period 1980 through 1995. He found that large fires tended to occur in areas dominated by annual grass cover (>50% herbaceous cover), at lower elevations than smaller fires (4,425 feet (1,341 m) average), and during a shorter fire season (July and August). More than half of all large fires were on relatively flat terrain (i.e. basins and foothills) that was historically more susceptible to invasion by nonnatives (i.e. ranch lands) and concurrently dominated by annual grasses. Because the annual grass/wildfire cycle is driven by positive feedback, these areas are also likely to experience large fires in the future. Large fires also occurred in more physiographically discrete regions than did smaller fires, with 8 specific regions representing approximately 60% of the overall Intermountain area, and representing the optimal combination of fuel amounts and fuel continuity for large fires (see [238] for more detail).

Cheatgrass fuels:

In the absence of grazing, grass biomass during the fire season may represent 2 years of fuel accumulation, which appears to be optimal for grassland fires [238]. Abundant, continuous cover of cheatgrass can lead to rapid spread of wildfires so that under conditions of high temperatures, low humidity, and wind, the fires are very difficult to suppress [476].

Brooks [69] compared the roles of nonnative annual grasses and other annual plants in facilitating the spread of fires in the Mojave Desert. Landscapes dominated by nonnative annual grasses, especially annual bromes (*Bromus*
spp.), are more flammable than those dominated by native forbs. Possible explanations for this include higher surface-to-volume ratio of grasses compared to forbs; more continuous vegetative cover; and the ability of alien annual grasses to remain rooted and upright longer than native forbs, allowing them to persist as flammable

fuels into the summer when the threat of fire is highest [69]. Thick layers of annual plant litter accumulate, and litter decomposes especially slowly in desert regions [69,487]. Accumulations of litter led to particularly hot temperatures, long flame residence times, and continuous burn patterns in experimental fires in the Mojave Desert [69].

Cheatgrass provides a flammable link between open grasslands and forests. It cures early in the fire season and ignites readily during dry periods because of its finely divided stems and pedicels, and it responds readily to changes in atmospheric moisture because of its fine structure. Moisture content is the single most important factor influencing cheatgrass flammability, and varies with plant phenology and color change as follows [314]:

Plant color	Moisture content (%)
green	>100
purple	30-100
straw	<30

Since there is considerable variation in plant coloration in a stand, close inspection is necessary to determine the predominant coloration. Cheatgrass is not readily ignitable until it reaches the straw-colored stage. The time required for the moisture content to drop from 100% to 30% ranged from 8 days on a northern exposure in western Montana, to 23 days on a southern exposure in different years, with an average of 14 days. The onset of purple coloring forewarns of hazardous fire conditions within about 2 weeks [314].

Cheatgrass ignites and burns easily when dry, regardless of quantity, and can support rapid rate of fire spread [73,235]. When cured and at 9% moisture content, each gram of cheatgrass material is capable of producing 3,900 calories to contribute to the spread of fire [368]. Flammability of cheatgrass fuels depends primarily on moisture content, weight, and porosity. Anderson [13] provides figures for equilibrium moisture content of cheatgrass litter under different conditions of relative humidity and temperature. Moisture diffusivity and response time in cheatgrass as fuel are given for different stand densities by Anderson [12]. When the moisture content reaches low levels (5 to 10% dry weight), variations in flammability are probably primarily caused by fuel weight and bulk density. Estimation of bulk density (weight per unit of volume of the fuel bed) is a practical aid in assessing the flammability of cheatgrass. Average bulk density for cheatgrass in western Montana was 0.00032 g/cm^3. More details are given by Brown [74]. Ratio of surface area to volume for several fine fuels is explored by Brown [75], and physical fuel properties of a cheatgrass fuel complex are given. Surface area:volume ratio for cheatgrass was 145 cm^2/cm^3.

Some mineral content and volatilization characteristics of cheatgrass leaves are given below [341]:

Silica-free ash (%)	Total ash (%)	Volatilization at 175-350 °C (%)	Maximum volatilization rate (µg °C)	Organic residue at 400 °C (%)
1.04	5.27	73	68	26

A basic procedure for evaluating the grass fuel models of the National Fire Danger Rating System is provided by Sneeuwjagt [395], with several examples from cheatgrass-dominated sites.

Fuel management/fire prevention:

On areas where cheatgrass is abundant, special measures may be necessary to prevent recurrent fires, and thus prevent the elimination of fire-sensitive perennial grasses and forbs [60] and other potential adverse impacts (see Fire Ecology and Impacts and Control for more information). Fire suppression can discourage invasion and spread of cheatgrass [365]. Grazing management to reduce fuel loads and greenstripping are 2 methods employed to prevent large recurrent fires in areas dominated by cheatgrass. Additionally, herbicides are being tested for effectiveness in creating fuelbreaks in cheatgrass-dominated range [412].

Cattle grazing can reduce the accumulation of cheatgrass litter and thus lessen the fire hazard on a site [137,335,491]. Grazing cheatgrass in winter can reduce cheatgrass herbage and seeds while protecting the dormant perennial grasses [137]. Davison [118] provides more detailed information on using livestock grazing to reduce fuel loads and subsequent fire occurrence and severity in cheatgrass-dominated rangelands.

Greenstripping is a method of establishing fuel breaks to impede the flow of wildfires and thereby increase the fire-free interval on a site dominated by cheatgrass. These fuel breaks are 30 to 400 feet (10-120 m) wide, and are seeded with fire-resistant vegetation. As of 1994, 451 miles (16,280 acres) of experimental and operational greenstrips had been established in Idaho. The effectiveness of greenstrips, or any fuels modification project, in reducing wildfire spread is enhanced by 3 factors: 1) disrupting fuel continuity (e.g. by replacing cheatgrass with caespitose grasses such as crested wheatgrass, which have large spaces between individual shrubs); 2) reducing fuel accumulations and volatility (e.g. shrub stands are thinned to maintain a minimum distance of 10 feet (3 m) between plants); and 3) increasing the density of plants with high moisture and low volatile oil content, thus reducing both the potential for ignition and rate of fire spread [335,336]. Plants used in greenstrips remain green and moist into late summer, making the greenstrip area less flammable for a longer time. Wildfire speed may slow when entering a greenstrip, thus allowing fire suppression crews to extinguish the fire. Some wildfires burn into greenstrips and extinguish [307]. Native plants in the Great Basin generally do not meet firebreak criteria [71]. Crested wheatgrass and forage kochia are effective in retarding wildfire spread, compete well in a weedy environment, and have been the most successful species in greenstrips [260,300,307,336]. Both plants can, however, be invasive and spread into areas where cheatgrass is being managed with prescribed fire [71,300].

Revegetation after cheatgrass fires:

After wildfires or when planning prescribed burning in areas where cheatgrass is present, managers must decide whether the burned area should be seeded or whether sufficient perennial grasses are present to revegetate a site and successfully compete with cheatgrass [371,487]. Seeding may not be necessary or desirable if native plant species are able to recover after fire [328,363]. Cheatgrass-dominated communities tend to have extremely sparse perennial seed banks, however, and the cheatgrass seed bank generally recovers by the 2nd postfire year [213,487]. In Utah, natural revegetation (no seeding) is most effective at higher elevations where sufficient moisture and a diverse population of perennial vegetation exist, especially on north- and east-facing slopes. Below 6,000 feet (1,820 m) and in much of Utah's arid environment, cheatgrass and other weedy species readily invade and dominate burned areas [260]. Seeding following fire may be needed to prevent cheatgrass dominance in Wyoming big sagebrush and pinyon-juniper communities, but not in mountain big sagebrush communities [168].

Revegetation of burned areas is desirable to assure forage for livestock and wildlife, and to minimize the potential for erosion and/or invasion by nonnative species. Ideally, wildfire rehabilitation should enhance the recovery of native vegetation through the seeding of native plants adapted to local environmental conditions. Native plants such as basin wildrye (*Leymus cinereus*), bluebunch wheatgrass, western wheatgrass, Indian ricegrass, big sagebrush, and fourwing saltbush (*Atriplex canescens*) have been used in rehabilitation seedings [328]. Early seral species such as bottlebrush squirreltail may provide managers with native plant materials that can successfully germinate and establish in the presence of invasive annuals [220,493] and do well after subsequent fire [271]. Bottlebrush squirreltail deserves consideration as a post-wildfire revegetation species because in greenhouse experiments, it has substantially greater growth in post-wildfire soil compared with unburned soil, and exhibits relatively higher growth rates in post-wildfire soil compared to cheatgrass [62]. Restoration projects using native species mixes to provide a variety of above- and belowground growth forms, and sowing at high densities, may increase establishment of desirable plants while providing adequate competition against invasive plants [71].

Monsen [301] discusses seed, seeding technology, and microenvironmental requirements for the reestablishment of big sagebrush weed-infested sites. Wyoming big sagebrush establishes readily from seed [78]. Establishment of bareroot Wyoming big sagebrush seedlings is most successful on fine-textured soils at Hanford in eastern Washington [130]. Colonization of sagebrush roots by mycorrhizae is much lower in burned sites compared with unburned sites; therefore, burning itself may impede the reestablishment of sagebrush over cheatgrass after fire [178]. Mycorrhizae are reduced by high-severity fires for about 2 years; therefore, establishment of sagebrush may be more successful 2 years after high-severity fires [259]. Reducing levels of available nitrogen immediately after fire may increase the rate of establishment by native plants and reduce the dominance of invasive annuals. Sucrose has been used experimentally to reduce nitrogen availability by increasing soil microbial biomass. Such treatments have reduced the growth of invasive plants while enhancing the establishment and composition of late-seral native plants in a semiarid ecosystem [277]. More research is needed to identify cost-effective techniques for reducing available nitrogen and enhancing the success of native plants [71]. Hardegree and others [183] discuss the development of technology to characterize seedbed microclimate as it pertains to the restoration and maintenance of native plant communities in sagebrush steppe, and how to use this information to design optimal planting scenarios for establishment of desirable native species and develop mitigating strategies to minimize competition from cheatgrass. Re-inoculation of components of biological soil crusts is also being explored in restoration efforts [219].

Federal policy currently encourages the use of native plant materials on public lands; but because the primary objective of wildfire rehabilitation on public lands is not ecological restoration but rather prevention of erosion and invasion by undesirable nonnative species, and because of the limited availability of native seeds, the use of native species is not mandatory for revegetation [71,328,371]. Roberts [371] summarizes some budgetary, ecological, and managerial concerns with regard to cheatgrass and pinyon-juniper fires. Because of difficulties related to cost, handling, and reliability of native seed supplies in wildfire rehabilitation situations, many managers prefer nonnative plant materials and traditional seeding methods.

Many large areas have been seeded with nonnative, herbaceous forage species [71,328,487] including crested wheatgrass, intermediate wheatgrass, tall wheatgrass (*Thinopyrum ponticum*), Russian wildrye (*Psathyrostachys juncea*), smooth brome, alfalfa, and yellow sweetclover (*Melilotus officinalis*). Seeds for these species are readily available and responsive to standard seeding methods; plants establish and grow rapidly, and have wide environmental tolerances. Many cultivars are also drought tolerant, grazing tolerant, and competitive against other, less desirable nonnative species [67,328]. The most reliable and persistent grass for low-elevation, drought-prone areas of the Intermountain West is crested wheatgrass. It establishes rapidly even under relatively dry conditions and tends to persist for many years [225,300,328], although some sites seeded to crested wheatgrass return to cheatgrass dominance over time [45]. Grasses that are most competitive against cheatgrass include 'Hycrest' crested wheatgrass, 'Luna' intermediate wheatgrass, 'Bozoisky' Russian wildrye, and smooth brome [3,4,158]. The competitive advantage for establishment of crested wheatgrass seedlings is lost if burned areas are not seeded the year of the fire [147]. Forbs such as alfalfa tend to have low persistence in rehabilitation seedings [300,328].

Cheatgrass suppression was best met by aerial seeding followed by chaining or drill seeding after large wildfires on rangeland in Utah. These methods can still result in large amounts of cheatgrass in the interspaces between seeded grasses [260,328]. Rehabilitation of cheatgrass burns has been attempted with disking, plowing, and other mechanical methods to reduce cheatgrass competition prior to seeding, but these methods obliterate any remaining native plants, especially perennial grasses and microbiotic soil crusts. Thus, these methods are not appropriate for wildland settings. As for soil stabilization, cheatgrass establishes more rapidly than seeded grasses and therefore may provide better soil protection in the short term [328]. Seeded bunchgrasses may not control soil erosion because of the large amount of bare soil in the interspaces between plants [253]. While perennial grasses and forbs reduce potential for recurring fire [300,336], perennial seedings are not immune to burning, especially when there is cheatgrass in the interspaces [328]. Finally, seeding nonnative species into burned areas should be carefully considered because nonnative species may have negative impacts on native vegetation and wildlife [191,304]. See Cultural control for more information on the relative merits of native versus nonnative plant materials for revegetation on rangelands.

Current goals of making wildfire rehabilitation objectives compatible with other management objectives on public lands may require careful planning of treatments and some modifications of standard practices, such as greater use of native plants [328]. The identification and use of competitive native perennial plants for arid-land rehabilitation has become a priority for managers and researchers [300]. In big fire years - such as 1996, when millions of acres burned - the scale of the demand for seed greatly exceeds the supply of native plant seed, especially of local genotypes. The competitive ability of nonnative species and the relatively low cost and high availability of their seed will continue to appeal to those faced with of large-scale burns in cheatgrass-prone areas [169]. If managers are able to predict large fires in advance (as per Knapp [238]), perhaps more efforts could be made to have more native seed available for specific sites.

MANAGEMENT CONSIDERATIONS

SPECIES: Bromus tectorum

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Cheatgrass was evidently widely distributed in arid and semiarid rangelands of Eurasia before the domestication of cattle. It is consumed by all of the native wild large herbivores on desert ranges there, and thus evolved with grazing pressure [246]. In North America, cheatgrass can tolerate repeated grazing, heavy trampling, and manuring. As long as it has time to set seed, it is likely to persist on grazed rangelands [116]. Cheatgrass abundance is not necessarily favored by heavy grazing, for it is highly palatable and is practically eliminated by uniformly heavy spring grazing [112,210,478]. Heavy spring grazing of cheatgrass both enhances its presence by weakening native cool-season perennial grasses, and suppresses its abundance by reducing seed production. Once it is present on a site, removal of livestock increases cheatgrass seed production and thus encourages its dominance [478].

From the standpoint of volume of herbage produced and extent of area covered, cheatgrass is undoubtedly the most important forage on grazing lands in the Intermountain and Pacific Northwest regions [438]. When it is green (usually in early spring), cheatgrass has excellent nutritive quality and supplies forage for all classes of livestock [111,438,478]. In years with average to above average precipitation, cheatgrass may provide more forage than is available on uninvaded range, especially in arid habitats (e.g. shadscale salt-desert community types) [476]. In these warm, dry regions, cheatgrass can provide important winter range for cattle [137].

Livestock:

There are several disadvantages of using cheatgrass as a livestock forage species including its short green feed period (usually about 6 weeks) [99,269,438], its declining forage quality and palatability as plants dry [99,111,210,269,478], and its tremendous variation in production among years [99,137,162,210,269,370,438,487].

Livestock gains on cheatgrass diets in spring are comparable to those attainable from most spring rangeland vegetation and decline to near zero once the cheatgrass plants mature [307]. When cheatgrass is dry, cattle and horses will still eat it, though levels of digestible protein and phosphorus may be inadequate, depending on the class of animal eating it [210,269,478]. Cheatgrass is a principal food on spring lambing ranges, but the pounds of dry matter consumed daily per sheep decreases sharply with increased maturity of cheatgrass [99,210].

Livestock grazing dry cheatgrass need to be closely observed, because eating dry cheatgrass herbage can greatly increase the incidence of mouth infections in cattle, and the sharp seeds can cause severe eye injuries [210,307,476].

Cheatgrass production varies and may be difficult to predict from year to year, as it is dependent on the amount and temporal distribution of moisture [99,111,210,238,269,334,370,438]. The grazing capacity of cheatgrass ranges can be high for part of the season. Of more importance to the livestock producer is the lack of cheatgrass production in dry years [210,269,487]. Hull and Pechanec [210] measured a 10-fold difference in cheatgrass production in consecutive years. The amplitude of variation in production may be greater for cheatgrass than for perennial natives, although a review by Young and Allen [478] suggests that as long as spring moisture is adequate, the variability in cheatgrass production is no greater than that of native perennial grasses. Forage production is especially reduced when cheatgrass germinates in spring rather than fall [478]. If germination occurs in fall and temperatures permit growth, the leaves can provide forage during fall and winter; if germination occurs late in fall, the plant remains in the rosette stage during winter and produces little harvestable forage until spring. If cheatgrass provides the bulk of a seasonal forage base, there is need to buffer the uncertainty of cheatgrass production [137]. In addition to fluctuations in production, the threat of large losses of cheatgrass forage due to wildfire is high [476,487]. Forage production of perennials can be twice the biomass of cheatgrass in a moist year, and 12 times the biomass during drought years [377].

Wildlife: Cheatgrass is often used as a green food and seed food by birds and wild mammals [184]. Several wildlife species utilize cheatgrass herbage for forage including bighorn sheep on winter ranges in Utah [166] and Colorado burns [399]; mule deer on spring and fall ranges [27,399]; pronghorn in western Utah [35] and southeastern Oregon [232]; Townsend's ground squirrels in Idaho [471]; and voles under snow cover in eastern Washington [264]. In eastern Washington the montane meadow mouse is the principle native grazer of both bluebunch wheatgrass and cheatgrass. Additionally, several other small mammals, birds, and insects (e.g. cottontail rabbits, black-tail jackrabbits, chukar, and grasshoppers) graze both species and can play a major role in shaping these plant communities [353].

Cheatgrass is a major component in the diet of many upland game birds, especially chukar, a nonnative game bird [476]. In summer and fall the bulk of chukar diets is composed of cheatgrass seeds. The range of chukar in the Great Basin has expanded as cheatgrass dominance has increased [381,452]. Cheatgrass was also consumed during seed maturity and senescent stages by 2 different grasshopper species in Idaho [152]. Grasshopper density was also higher in annual grasslands dominated by cheatgrass and medusahead compared with vegetation types with shrub cover in Idaho [153].

Palatability/nutritional value: Reviews by Mosley and others [307] and Upadhyaya and others [438] suggest that cheatgrass is palatable and nutritious for all classes of livestock and many species of wildlife, especially in spring and sometimes in mild winters. Cheatgrass compares favorably in nutritional quality with most native and introduced perennial grasses that it grows in association with.

The following table provides chemical composition of cheatgrass growing in western and northern Utah ranges at different growth stages [99]:

Stage of growth	Ether extract (%)	Total protein (%)	Lignin (%)	Cellulose (%)	Other carbohydrates (%)	Total Ash (%)	Calcium (%)	Phosphorus (%)	Gross energy (kcal/lb)
boot	2.7	15.4	4.1	27.4	40.2	10.2	0.64	0.36	1,964
head	2.1	11.1	4.4	30.6	41.5	10.3	0.60	0.32	1,973
dough	1.8	8.2	6.3	33.4	39.8	10.5	0.53	0.27	1,914
early seed	1.6	7.4	8.4	28.3	43.6	10.7	0.51	0.26	1,805

late seed	1.3	6.1	10.4	32.4	38.8	11.0	0.56	0.21	1,878

Ganskopp and Bohnert [162] characterized seasonal and annual nutritional dynamics of 7 grasses (including cheatgrass) in the Great Basin, at 6 sites over 2 years (a year of below-average precipitation followed by a year of above-average precipitation). They concluded that rangelands with a diversity of grasses that exploit all levels of the soil profile provide forage for longer time periods than pastures relying on a single species.

In samples taken from 6 sites around Burns, Oregon, crude protein (CP) and in-vitro organic matter disappearance (IVOMD) levels in cheatgrass peaked in late April (~15-22% and ~76-82%, respectively), declined rapidly from late April to late June, and were lowest in the fall and winter months (around 2%). October 1992 was an exception, when levels increased following precipitation of 57 mm. CP levels tended to be higher than Sandberg bluegrass, bottlebrush squirreltail, Idaho fescue, bluebunch wheatgrass, and Thurber needlegrass, but lower than giant wildrye. IVOMD was higher for cheatgrass than other grasses and exhibited the greatest range of seasonal change. Neutral detergent fiber (NDF) was lowest in cheatgrass in late April (38.5%), with a high degree of variation between months and years. NDF was highest in fall and decreased after the October precipitation event [162].

Austin and others [27] found cheatgrass was 1 of several annual grasses that are nutritionally valuable to mule deer in spring and fall in Utah, with 72.2% digestible dry matter, and 21.2% CP. Bishop and others [49] compared the nutritional quality (in-vitro dry matter digestibility (IVDMD) and CP) of cheatgrass among 3 mule deer winter ranges and among 6 habitat components in southwest Idaho. Cheatgrass quality varied significantly (p=0.002) between winter range sites, but not within sites. IVDMD ranged from 65.8 to 69.9%, and CP ranged from 16 to 17%.

Cover value: No information

OTHER USES:
Bean and Saubel [36] suggest that the Cahuilla considered cheatgrass a famine food. Seeds were gathered in quantity and cooked into gruel.

IMPACTS AND CONTROL:
Impacts:
The impacts of cheatgrass invasion vary with plant community and degree of cheatgrass dominance. At low densities, cheatgrass may simply be a part of the understory. At high densities, cheatgrass dominance can lead to complete community type conversions from perennial bunchgrass, sagebrush, salt-desert shrub, or pinyon-juniper communities to cheatgrass monocultures. The presence and dominance of cheatgrass affects many aspects of community structure, process, and function including diversity of plant and animal species, disturbance regimes, succession to other undesirable nonnative plants, nutrient cycling, and soil attributes. These changes may require substantial human intervention to convert to more desirable ecosystems.

Impacts on native plants: Cheatgrass is very persistent across a range of habitats [93,112,114], and can displace both rare and common plant species, thus reducing the number and genetic diversity of native plants in invaded communities. These changes can result from direct competition, from increased fire frequency, and possibly from indirect effects of changes in plant litter dynamics, nutrient cycling and soil ecology [377]. Soil water depletion is one of the principal mechanisms that allows cheatgrass to successfully compete with perennial grasses [138,281] and may negatively impact root growth of native species [280], especially during the establishment of perennial grass seedlings. Cheatgrass has been shown to deplete soil moisture and reduce growth of natives such as Idaho fescue [316], bluebunch wheatgrass [3], green rabbitbrush, and needle-and-thread grass [281]. It has also been observed to impede the establishment of native seedlings such as big sagebrush, green rabbitbrush, antelope bitterbrush [132,144,476], Stansbury cliffrose (*Purshia mexicana* var. *stansburiana*) [352], and several perennial herbaceous species [373]. Wallace and Nelson [447] suggest that cheatgrass infestations may contribute to shrub die-off in western rangelands. Introduction of cheatgrass and heavy grazing of native perennials have irrevocably altered the understories of Oregon white oak woodlands in the eastern Cascades [2]. A review by Mosley and others [307] suggests that plant biomass production on cheatgrass-infested rangeland is substantially less, and much more variable from year to year, than on rangeland dominated by native vegetation.

Cheatgrass can supply reasonably good forage and ground cover when desirable perennials are removed, although production is unpredictable and unreliable [59]. For details on cheatgrass' impacts on forage availability see Importance to Livestock and Wildlife. It has been suggested that in the absence of burning or heavy grazing, cheatgrass can help prevent erosion, promote water infiltration, and increase soil organic matter as a result of litter accumulation on areas where perennial cover has been reduced [1,210,406,454]. On the other hand, cheatgrass litter provides the fine fuel that can lead to wildfires, which may ultimately lead to plant community type conversions, subsequent impacts on wildlife, and the proliferation of other nonnative plants.

On the Snake River Plain, as in many areas throughout the Columbia River Basin and the Great Basin, the introduction of cheatgrass and other annual grasses, such as medusahead, has altered fuel loads and fuel distribution, which in turn has changed fire frequency, intensity, severity, timing, and extent [78,239,340,406,461,476,484,487,492]. For more information on fire regime changes in cheatgrass dominated ecosystems, see Fire Ecology. These fire regime changes, coupled with the impacts of domestic livestock grazing, have greatly modified plant recruitment, species composition and distribution, and the physiognomy and functioning of many vegetation types within the Intermountain West [71,340,365,461]. Several plant communities that are not adapted to the frequent fires that cheatgrass infestations engender have become increasingly susceptible to loss by wildfire. Examples include old growth pinyon-juniper woodlands [295], vast areas of sagebrush steppe (e.g. [239,340,461,484]), extensive stands of antelope bitterbrush in south central Idaho, central Utah, Oregon, and southern California [300], and salt-desert shrublands that often have high numbers of endemic plant and animal species [59,71].

Cheatgrass alters successional trajectories of postfire plant communities by interfering with native seedling establishment [3,132,144,281,316,352,373,406,476], by competing with established perennials for resources [138,280,281], and by shortening the interval between fires [48,261,406,455,461,487]. The ecological consequences of repeated burning include reduced species diversity, as the proportion of annuals in the community increases at the expense of other life forms [340,461]. In the desert shrublands of North America, individual fires may not have serious lasting effects, but recurrent fires may lead to resource homogenization that can complicate restoration efforts. More research is needed to determine how widespread this process is and to develop management tools to mitigate its effects [71].

The vitality and integrity of several native, fire-sensitive communities has been so reduced by repeated wildfires that extensive areas of shrub and perennial grass communities have been converted to annual grasslands [287,461,483,484,487,492]. Knick [239] reports rates of loss of big sagebrush and native salt-desert shrub communities in the Snake River Birds of Prey National Conservation Area in southwestern Idaho. In 1979, 250,000 acres (100,000 ha), or 51% of the total area, was comprised of big sagebrush and native salt-desert shrub communities. Because of fires and other disturbance, only 145,000 acres (58,000 ha) of shrubland remained in 1994, and another 30,000 acres (12,000 ha) of shrublands burned by 1998. Shrubland losses of this magnitude are typical of many sagebrush ecosystems in lower elevations and in xeric climates throughout the Columbia River Basin and Great Basin [71,239,340,461,492]. Monsen and Shaw [304] report "cheatgrass invasion has completely transformed ecological communities on millions of acres in the sagebrush grasslands of North America."

Despite the trend of improving range conditions on Intermountain rangelands attributed to improved grazing management [487], the dominance and distribution of cheatgrass has continued to increase in various rangeland ecosystems of the Intermountain area. This continuing increase in cheatgrass is attributed to grazing management systems that favor cheatgrass establishment [477] and to the increasing role of wildfire [48,71,239,340,461,475,492]. Some of the native plant and animal species in ecosystems that are now prone to widespread wildfires due to the presence of cheatgrass are at considerable risk of going extinct at the population level: locally or even regionally. This implies a threat to the existence of large, integrated ecosystems that have existed since the Pleistocene in the relatively arid lands between the Sierra Nevada and Rocky Mountains. The results could be the conversion of these native ecosystems to annual grasslands lacking not only the native vertebrates but also those invertebrates and biologic soil crusts that are involved in the energy flow, water cycling, and nutrient balance of the ecosystem [48].

Impacts on wildlife:

Vegetation type conversion can affect wildlife ranging from herbivores to carnivores and reduce overall biodiversity [71]. While fires at low to moderate severities on sites with good productivity, deep soils, and good native plant components can benefit some wildlife habitats, high-severity wildfire in sagebrush-annual grass rangelands is considered detrimental to most wildlife species, as it promotes dominance of nonnative annual grasses and high fire frequency [418]. Large-scale change in structure of plant communities of this type can cause reductions in suitable habitat and concomitant shifts in the abundance of some species of birds [383] including Brewer's and sage sparrows and sage-grouse [94,239]. Areas in which sagebrush has been removed may not be used by nesting or brood-rearing sage-grouse until sagebrush re-establishes [97,234] (see sage-grouse).

Cheatgrass fires can adversely affect wildlife habitat by eliminating important forage species such as antelope bitterbrush on elk and mule deer winter range in Lassen County, northeastern California, and in northwestern Nevada [92,439]. The habitable winter range in this area is relatively small, so when fire promotes cheatgrass and reduces scattered foothill clumps of antelope bitterbrush and sagebrush, browse, thermal cover, and hiding cover are reduced [252]. Additionally, the length of time that cheatgrass is green and actively growing is shorter than that of native perennial vegetation. Thus compared to native species, cheatgrass dominance reduces the green-feed period for foraging animals [307].

Conversion of sagebrush habitat to cheatgrass is associated with a decline in densities of black-tailed jackrabbits [241], Townsend's ground squirrels [472], and other small mammals [164,176]. Two factors may limit small mammal populations after fire: 1) the loss of shrub cover may result in increased predation, and 2) thick stands of cheatgrass may impede small mammal movements which may affect breeding success and population size [176]. Similarly, dense cheatgrass can blockade newly hatched ducklings from making the vital trek from upland nest to lowland water [252]. Because cheatgrass-dominated communities support fewer small mammals than shrub-dominated communities, predator species such as the gopher snake, coyote, badger, and raptorial birds are also affected by large-scale losses of shrub habitat [161,241]. Loss of small mammals results in an increasingly unstable prey base for raptors in the Snake River Birds of Prey Area [161,472] and elsewhere. Kochert and others [241] have also documented that golden eagles avoid previously burned areas, and that golden eagle fledging success declines as the extent of burned area increase in their territory. Slow-moving fauna such as desert tortoises are sometimes killed in rapidly moving fires such as those that burn in cheatgrass [492]. The effective management of many wildlife species can depend on the control of invasive plants like cheatgrass and in the maintenance of appropriate fire regimes [71].

Other nonnative invasive species:

Rangelands dominated by cheatgrass may also be susceptible to establishment of other nonnative, invasive annual grasses such as interrupted windgrass, corn brome, little lovegrass, poverty grass, and ventenata that are already present in the Pacific Northwest and are capable of invading and naturalizing in cheatgrass-infested areas [318]. The concept of a cheatgrass stand being a community closed to the establishment of perennial species [373] is challenged when one considers nonnative perennial and annual species that have invaded cheatgrass stands such as bur buttercup, forage kochia [198,476], squarrose knapweed [374], spotted knapweed, diffuse knapweed, rush skeletonweed, leafy spurge, common St. Johnswort, Dalmatian toadflax [187], yellow starthistle [187,306], and medusahead [187,189,196,295]. Medusahead has invaded and replaced dense stands of cheatgrass [189,295] over large areas in California, Idaho, Oregon, and Washington during the past 40 years [196]. Medusahead herbage is less palatable to ungulates, thus reducing grazing capacity where it replaces cheatgrass [187], and its seeds are not digestible by upland game birds, which are large consumers of cheatgrass seeds [381]. Evans and Young [141] suggest that cheatgrass enhances seed germination of several nonnative species in desert shrublands because of improved water availability associated with cheatgrass litter.

Impacts on soil resource:

On ranges in which sagebrush and other native species have been eliminated by recurrent fires, cultivation, or grazing and now support nearly pure stands of annual grasses or weeds, soil losses can be severe [60]. A review by Upadhyaya and others [438] suggests that cheatgrass fires may leave land vulnerable to soil erosion because cheatgrass burns so completely. Cheatgrass litter may affect the rate and quality of nutrient cycling differently than native species, although more research is needed to understand these dynamics [62]. Nutrients may cycle faster in systems dominated by cheatgrass because its fine above- and belowground plant material can decompose quickly and because infested areas burn frequently, releasing minerals rapidly [326]. MacDonald [260] suggests that because cheatgrass does not catch and hold snow like a diverse perennial stand of vegetation, the site becomes drier. Cheatgrass dominance and associated fires also reduce populations, diversity, and recovery of biological soil crusts, which affect nutrient cycling, water infiltration, and potential soil erosion. When annual nonnatives dominate the plant community, the makeup of biological soil crusts changes, and their reestablishment is impaired [41].

The impacts of cheatgrass on ecosystems that it now dominates are such that the goal of managing vegetation to reflect conditions thought to have been present before European settlement may be impossible. Even the concept that preservation of native plant communities will prevent, eliminate, or control cheatgrass is not supported by evidence from sites in Utah [167]; in other areas where cheatgrass has displaced native bunchgrasses and shrubs in Great Basin; and where it continues to dominate sites in southeastern Washington, almost to the total exclusion of native grasses [326]. Dominance of cheatgrass and medusahead will not be changed simply by removing cattle or reducing their numbers [325]. The decision to reclassify vegetation types and to manage for cheatgrass instead of native perennial grasses may be considered for areas with sparse stands of desirable perennials [487] that are dominated instead by cheatgrass, halogeton, and/or medusahead. In such situations neither complete protection nor conservative grazing can restore a desirable cover within a reasonable period because a seed source of desirable species is lacking and competition from the undesirable plants is severe [60].

Control:

Because cheatgrass is very persistent once it becomes established, eradication of large infestations is not usually a reasonable goal. The extent to which cheatgrass dominates a plant community greatly determines the appropriate suppression strategy [274,307], and cheatgrass response to management options is very site specific [189,478]. Some current research on control and management considerations for cheatgrass was presented at the Cheatgrass Awareness Conference in February 2003. Summaries and presentations are available online (Cheatgrass Awareness Conference).

Care must be taken with methods employed to control cheatgrass so that any void left by cheatgrass removal is not filled with another nonnative invasive species that may be even less desirable. A thorough site reconnaissance and evaluation is recommended before initiating any form of plant control.

Monitoring is an important part of weed management [218], as are early detection and local eradication of new infestations [497]. Estimates of cheatgrass coverage should be designed to determine how dominant cheatgrass is in an area compared to other vegetation. Areas should be monitored every spring, and relative cover and boundaries of any infestation should be recorded. Special attention should be paid to roadsides and other disturbed areas where cheatgrass is commonly found. If an infestation is found, the location should be recorded and monitored to measure the rate in which the infestation is spreading. Determining the relative cover of cheatgrass can be difficult due to the fluctuations in cover between years in accordance with weather variation [84]. Tueller [433] discusses the use of remote sensing to extract information about burns and annual vegetation patterns in the sagebrush grass ecosystems of the Great Basin relative to cheatgrass dominance.

Information regarding the extent of cheatgrass dominance in comparison to native species can be used to decide appropriate management strategies. Strategies may range from protection of areas not yet invaded, to reclassification of areas dominated by cheatgrass and management of these areas as cheatgrass rangelands. Intermediate to these states are areas with varying densities of cheatgrass, many having the potential to be converted to annual grasslands after fire. A review by McIver and Starr [274] suggests that "restoration" requires not only the reestablishment of historical plant community structures and species compositions, but also of the processes needed to sustain these into the future. It may be difficult to predict the outcome of control efforts or changes in disturbance regimes at any given site because native plant species respond differently to disturbance events [270,274].

Once cheatgrass is established, complete protection from grazing or other disturbances will not usually reduce cheatgrass abundance. Protection from all grazing can in fact increase the chance for fire and cause subsequent increases in cheatgrass dominance [461,478]. A mountain big sagebrush/bluebunch wheatgrass site in southwestern Idaho that was invaded by cheatgrass and subsequently protected from further disturbance continued to be dominated by cheatgrass for decades. Perennial grasses recovered slowly in protected areas, requiring more than 45 years to increase in cover from about 1.4 to 6.7 % [298].

Effective control of cheatgrass requires 1) eliminating live plants, 2) preventing seed formation, and 3) controlling seed germination and emerging seedlings [300]. In plant communities where cheatgrass is present but herbaceous perennials remain abundant, cheatgrass control measures should include the needs of the perennial plants. Control without replacement by desirable perennials will likely result in the reestablishment of cheatgrass or some other undesirable species [307]. In order to maintain dominance on a site, cheatgrass must produce a viable seed crop each year. If not, perennial plants can pre-empt the site. On the other hand, only a few perennial grass seedlings need to establish each year to maintain a perennial stand if mortality in established plants is not excessive [189]. Grazing management to favor native perennial grasses is doomed to failure unless there are sufficient perennial grasses in the ecosystem to outcompete cheatgrass. It is inappropriate to manage cheatgrass ranges as if they were perennial grass-dominated ranges [476].

Large areas that are mostly devoid of perennials and have fire-free intervals of 5 or fewer years have probably crossed a threshold, and the cheatgrass community probably represents a relatively stable "steady state" [251,307], such as exists on many depleted sites within Wyoming big sagebrush habitat types of the Snake River Plain and other portions of the Columbia River Basin [307]. For such sites only aggressive methods may have a chance of restoring more desirable sagebrush steppe communities [251,379,440]. Some authors suggest that it may be best to reclassify these communities as annual grasslands, and manage them accordingly [440,487].

Prevention: The most important aspect of invasive species management is prevention [191,388]. Whether or not cheatgrass establishment can be prevented in arid and semiarid rangelands is uncertain. It has been suggested, however, that maintaining an adequate cover of native plant species [14,59,112] and biological soil crusts [41] can render some communities more resistant to cheatgrass invasion. Managers must be aware that cheatgrass is especially prevalent in the early stages of fire succession or following other disturbances when shrubs, trees, perennial grasses, and other invasive plants are removed [34,34,122,139,145,210,273,291,295,382,388,396], and that cheatgrass density can increase dramatically 2 to 3 years after disturbance.

Proper grazing management may be an important tool in preventing or delaying further encroachments of cheatgrass into perennial vegetation [59,60,175,440].

Management practices that maximize the amount of organic debris left onsite and minimize the period of time between vegetation removal and reestablishment can limit the establishment of invasive plant species [400].

Integrated management:

Once established, cheatgrass can rarely be controlled or eradicated with a single method, and most researchers and managers recommend combining physical, biological, chemical, and cultural control methods in some fashion [492]. Individual control methods (e.g. disking, herbicides, and prescribed fire) have limited application for control of cheatgrass on rangeland, and are more effective when used as site preparation for revegetation with desirable species [307].

Controlling live cheatgrass plants and the existing seed bank requires a combination of treatments conducted over a 1- to 2-year period. For example, mature plants can be killed before seed dispersal in spring by tilling or burning, with fall tillage or herbicide application as a follow-up treatment to eliminate any new seedlings. Artificial seeding of desired species is then conducted in the late fall or early winter [300]. Another strategy is to use prescribed fire in autumn to prepare sites for seeding the following spring [78,307,362]. Disking, herbicides, or prescribed livestock grazing can then be used in late spring to reduce vigor and seed production of the cheatgrass plants that establish after the fire. Seeding the site can be delayed until after the disking, herbicide, or prescribed grazing treatment, or the site can be broadcast-seeded immediately before grazing treatment, in order to use livestock to trample in the seed [307]. Another effective approach combines summer burning, when the majority of cheatgrass seeds were still held in the inflorescences, followed by fall herbicide application after cheatgrass seedlings have emerged [180]. It is unclear how long reductions of cheatgrass may last. Harris and Goebel [189] suggest that burning alone is usually not enough to destroy seeds, but can be combined with mechanical or chemical treatment to improve effectiveness.

Sheley and others [389] provide examples of successional weed management systems that integrate various control techniques to direct successional processes, resulting in different successional patterns and usefulness to range managers. The resultant plant community is dependent on the specific weed management system and the plant community prior to weed management [388,389].

On the Lawrence Memorial Grassland Preserve in Oregon, combinations of prescribed burning, herbicide applications (glyphosate), and mowing treatments were used to prevent cheatgrass and medusahead seed maturation. Preliminary results indicate that glyphosate treatment, and summer prescribed burning followed by mowing the next year, were equally effective at reducing invasive annual grass cover [349]. A multi-state, interdisciplinary research project has been proposed to examine integrated restoration strategies on western rangelands [323].

Physical/mechanical:

Mixed results are reported for controlling cheatgrass with physical methods such as hand pulling, cutting or mowing, and disking or tilling. Tillage is often cited as an effective control method when combined with other methods; however, such intensive treatments are not usually appropriate for natural areas or wildlands and often lead to establishment of other undesirable plants. Regardless of which method is used, the cheatgrass seed bank must be depleted to get effective control [84].

In small areas, hand pulling can effectively control cheatgrass [365].

Cutting or mowing is not a recommended control method for cheatgrass unless it can be repeated several times per year, for several years. Plants that are cut before seed ripening can generate new culms and produce seeds at the cut height. Plants that are cut after seed ripening will still leave viable seeds [154,349]. Because seeds may be viable as early as the dough stage, before any purple coloration appears, there is only a short period after inflorescences appear that the plants can be mowed without danger of dispersing viable seeds. Therefore there is no single phenological stage that can be mowed which will assure complete kill or absence of seeds [207]. Cutting cheatgrass plants along trails before seeds are ripe and throughout the season can reduce spread of the invasion. Cutting cheatgrass plants for 3 consecutive years reduced densely populated areas at the Northeast Preserves in Oregon [365]. Repeated mowing (every 3 weeks) during the spring and summer was as effective at controlling cheatgrass seed production as was an application of glyphosate, though it was very labor intensive [349].

A review by Mosley and others [307] suggests that tillage and other mechanical control methods applied alone are often ineffective for controlling cheatgrass on rangeland. To be effective, tillage must be 4 to 6 inches

(10-15 cm) deep to bury cheatgrass seeds in the soil and prevent them from germinating. More than 1 tillage treatment is usually needed, because the tillage equipment does not consistently cut deeply enough to bury the seed. To effectively suppress cheatgrass, tillage must be followed by sowing of desirable plants [307]. Tillage is not usually appropriate in wildlands and rangelands since it can damage important desirable species, increase erosion, alter soil structure, and expose soil for rapid invasion of cheatgrass and other invasive plants.

Fire: See Fire as a control agent for cheatgrass.

Biological:
No insects or fungi have been approved by the USDA for use as biological control agents for cheatgrass. Cheatgrass is often infected with a head smut fungus (*Ustilago bulleta*) that may reduce seed yield when severe. Meyer and others [288] are exploring whether using this fungus may be feasible for biocontrol of cheatgrass. Some research has been conducted on the potential of pink snow mold (*Fusarium nivale*) as a control agent. In addition to these fungi, over 20 diseases of cheatgrass have been reported [492]. Kennedy [230] summarizes developmental research on the use of soil bacteria from the genus *Pseudomonas* as biocontrol agents for cheatgrass. Reviews by Carpenter and Murray [84] and Mosely and others [307] suggest that these microbes colonize the seeds and roots of cheatgrass and produce a toxin that appears to inhibit cell elongation in the growing plant. The toxin may also inhibit cheatgrass germination and seedling vigor. One particular strain, *P. fluorescens*
D7, inhibits several biotypes of cheatgrass from throughout the world. This strain of bacteria also attacks other species in the *Bromus* genus.

Livestock grazing can reduce cheatgrass cover [45,116,343] and can be purposely manipulated to control cheatgrass [112,308,440], although some authors recommend against it (e.g. [137]). This tool is probably best suited to localized areas, either for protecting existing stands of perennial plants from fire, or for aiding the artificial seeding of severely depleted sites [308].

To prevent seed production, Mosely [308] recommends that cheatgrass plants be grazed before they turn purple in color. At least 2 defoliations are needed in the spring of each year, for a minimum of 2 consecutive years, to control cheatgrass [308]. Clipping was used experimentally to simulate grazing for cheatgrass control. Late spring clipping had the largest reduction in both density and biomass of cheatgrass compared to fall and early spring clipping or clipping in early spring only [414]. On salt-desert shrubland in western Utah, cheatgrass cover remained the same over 50 years on ungrazed range. It increased only very slightly on range grazed by domestic sheep in the fall, while spring grazing tended to increase cover of cheatgrass in general [460].

Prescribed domestic sheep grazing can be used to suppress cheatgrass density, growth, seed production, and mulch accumulations [111,112,116,308]. This is more easily accomplished in areas devoid of desirable perennials than in areas where remnant desirable perennials are present and need to be protected [308]. Where desirable perennials are present, grazing intensity should be light enough so that desirable grasses have a residual stubble height of 3 inches (8 cm) or more [308]. Grazing dried cheatgrass during winter dormancy will help reduce mulch accumulations and enhance seedling establishment of perennials. Grazing intensities in winter can be moderately heavy without damaging desirable plants, if soils are dry and firm [307]. Grazing in late autumn, when herbaceous plants are dormant, can reduce sagebrush density and enhance the ability of perennial herbs to compete with cheatgrass and sagebrush [308]. Encouraging reestablishment of native plants improves the effectiveness of grazing as a control method [492]. Where cheatgrass is a problem in bluebunch wheatgrass communities, properly timed grazing (before the boot stage of bluebunch wheatgrass, which coincides with shoot and flower development of cheatgrass) for a short duration is a helpful control technique [293]. Mixtures of crested wheatgrass and cheatgrass soon become dominated by crested wheatgrass if grazing on the area is well managed [406]. Prescribed domestic sheep grazing can also be combined with prescribed fires, herbicides, disking, and broadcast seeding [308].

In mixed stands with desirable perennials, livestock grazing can be directed to 1) reduce cheatgrass competition by concentrating grazing of cheatgrass during the dough seed stage, providing perennials have the opportunity to complete their life cycle, or 2) focus grazing on the needs of perennials while mostly ignoring cheatgrass [440]. Daubenmire [112] noted that cheatgrass did not dominate under heavy grazing pressure during spring, when livestock feed on the plants so heavily that no seeds matured. In this case, scattered plants may escape grazing, and when animals are removed, cheatgrass quickly dominates the area. Excessive grazing in the early spring, year after year, weakens the native cool-season perennial grasses, thereby providing habitat for cheatgrass to spread, but it also reduces abundance of cheatgrass. "The fact that excessive spring grazing both enhances the presence and biologically suppresses the abundance of cheatgrass is one of the most misunderstood aspects of the biology of this grass" [478].

Sanders [379] suggests that annual rangelands receiving 14 or more inches (356 mm) of annual precipitation can be converted to perennial rangeland through grazing management, providing there are sufficient perennial plants present as a seed source. Even in this precipitation zone, however, conversion seldom occurs without some means of reducing the annual grass competition (herbicides, fire, heavy spring grazing). Sanders adds that there is little evidence that annual rangelands receiving less than 12 inches (300 mm) of annual precipitation can be converted through grazing management alone [379].

Fire-free intervals can be lengthened by using prescribed domestic sheep grazing to disrupt fine-fuel continuity and reduce fine-fuel loads [308]. Grazed firelines should be at least 250 feet (75 m) wide [307,469].

Chemical:

Several herbicides have been used alone or in combination to provide effective control of cheatgrass, including quizalofop, fluazifop-p-butyl, sethoxydim, paraquat, glyphosate, imazapic, sulfometuron methyl, and atrazine [84]. Carpenter and Murray [84] give more details and contacts in various states with specific chemical control information (see The Nature Conservancy's Wildland Invasive Species Team website to view this document online). The Weed Control Methods Handbook has detailed information on some of these chemicals as well [432].

Chemical control can be used effectively when desired perennial plants are still abundant. One year of chemical application will only temporarily thin the cheatgrass population and may actually increase cheatgrass seed production. Treatment must be repeated from 2 to 5 years consecutively. Several newer herbicides, especially imazapic, are being tested for selective control of cheatgrass in perennial broadleaf seedling stands [492]. Summaries of some current research on the use of imazapic for cheatgrass control are available (Cheatgrass Awareness Conference).

Sulfometuron methyl has been used to control cheatgrass on rangelands for 1 to 2 years and thus improve the success of rehabilitation projects. Projects in Nevada and Idaho comparing sulfometuron methyl treatment with burning and disking are summarized by Pellant and others [338]. There are various restrictions associated with sulfometuron methyl use. Ongoing and available studies include rates, season [56], effects of sulfometuron methyl on survival and reproduction of native plants and biological soil crusts, and effects on seeded perennial plants [56,338]. Spring treatments were considerably less effective; and damage to native bunchgrasses (Sandberg bluegrass and bottlebrush squirreltail) occurred with high application rates in spring [387]. Other studies explore the effects of combining chemical control with prescribed burning and seeding of desirable plants [131,132,143,444,463,480].

Some cheatgrass biotypes have evolved resistance to herbicides including atrazine, simazine, chlorotoluron, primisulfuron-methyl, and sulfosulfuron; and may be cross-resistant to other photosystem II inhibitors, urea, amides, and/or acetolactase inhibitors. More information on herbicide resistance is available at WeedScience.org.

Chemical control of other invasive species can result in increases in cheatgrass. For example, the use of 2,4-D alone to control spotted knapweed resulted in an increase in biomass and cover of cheatgrass, while the use of 2,4-D and grazing by domestic sheep resulted in lower biomass and cover of cheatgrass compared to treatment with 2,4-D alone [249]. Similarly, application of clopyralid to control yellow starthistle can increase cheatgrass cover [122].

Cultural:

Cheatgrass is not competitive with established perennials, particularly grasses; therefore, biological suppression with desirable perennials may be an effective method of controlling cheatgrass [492]. Because cheatgrass seedlings can outcompete seedlings of most perennial species and prevent their establishment, successful establishment of desirable perennials 1st requires the depletion or removal of cheatgrass plants and seed bank [138,307,373]. Robertson and Pearse [373] suggest that openings in cheatgrass communities caused by severe drought, fire, or grazing can provide conditions favorable for artificial reseeding with desirable species, provided sufficient soil remains. Evans [138], however, found that as few as 4 cheatgrass seedlings per square foot (43/m^2) can inhibit survival of crested wheatgrass seedlings, implying that is necessary to achieve near-perfect cheatgrass control for successful perennial seedings [140,147,373]. Techniques for accomplishing this are presented in the above sections. Haferkamp and others [180] examine several different seedbed preparations and seeding methods on sites in Washington and Oregon. Effectiveness of these techniques varies widely, depending on terrain, local weather conditions, treatment timing relative to cheatgrass development, and recovery of annuals from residual seed reserves left near the soil surface where they are capable of germinating [387]. For information regarding revegetation after prescribed burning or wildfire see Fire Management Considerations.

Young [477] summarizes the history of revegetation programs in the West, comparing species, sites, and ecosystems. Monsen and McArthur [302] provide a discussion of the history of revegetation projects in the Intermountain West, including constraints and benefits of using native and nonnative species. Most attempts to artificially seed big sagebrush ranges with native grasses prior to 1945 were largely unsuccessful. The introduction of crested wheatgrass, a nonnative, drought-tolerant perennial grass, made large-scale seeding of sagebrush ranges possible. From 1945 to 1965, several million acres of sagebrush rangeland were seeded to crested wheatgrass in the Intermountain area. Cheatgrass distribution was limited by extreme grazing pressure at that time, so these seedings took place in seedbeds with limited cheatgrass competition. The universal grazing management systems that followed ultimately favored cheatgrass establishment (see [477] for details). Subsequent increases in the distribution and density of cheatgrass now precludes the successful establishment of crested wheatgrass and other perennials without prior cheatgrass control on most of these sites [477].

Crested wheatgrass is a reliable and persistent grass for low-elevation, drought-prone areas of the Intermountain West. It establishes rapidly even under relatively dry conditions and tends to persist for many years [225,300,328]. It is best adapted to the sagebrush grassland portions of the Intermountain range, but not to salt-desert ranges [373]. While studies have indicated that cheatgrass is a superior competitor to crested wheatgrass [3,23,26,158,190,208], they have also indicated that crested wheatgrass competes more effectively with cheatgrass than does bluebunch wheatgrass [3,136,190].

In addition to crested wheatgrass, several other nonnative, herbaceous forage species have been used for revegetation and cultural control efforts, with limited to mixed success [67,71,117,328,487]. A long-term study to identify the species best suited to seeding semiarid rangeland sites in northeastern Washington indicated that hard fescue (*Festuca trachyphylla*) was the most aggressive competitor, and cultivars of crested wheatgrass provided the highest yields. Several other grasses were also tested and compared, and results are presented by Harris and Dobrowolski [188]. A review by Mosley and others [307] provides the following summary: 'Hycrest' crested wheatgrass, 'Sodar' streambank wheatgrass (*Elymus lanceolatus*), and 'Luna' intermediate wheatgrass are most suitable on unirrigated sites where annual precipitation is 12 to 16 inches (300-400 mm). 'Regar' meadow bromegrass (*Bromus biebersteinii)* and orchardgrass (*Dactylis glomerata*) are suitable for reseeding most cheatgrass-infested rangeland where annual precipitation exceeds 16 inches (400 mm), although orchardgrass can also be invasive. Drought-resistant species such as 'Hycrest' crested wheatgrass and Siberian wheatgrass (*Agropyron fragile*) are most suitable in areas receiving less than 12 inches (300 mm) of annual precipitation, although successful establishment on such dry sites is especially difficult [307]. Native grasses are more difficult to establish, less persistent, and less productive than nonnative grasses on sites with less than 10 to 12 inches (254-300 mm) of annual precipitation [24,300]. Mountain rye (*Secale montanum*) was seeded on reclaimed coal mined lands in southeastern Montana to suppress cheatgrass and Japanese brome (*Bromus japonicus*). It was effective for short-term suppression (2 years), but not for longer-term control [10,11].

Some managers are experimenting with another nonnative plant, forage kochia, for use on severely altered semiarid rangelands that support monocultures of cheatgrass and/or tumblemustard and are subject to repeated fires in Nevada [90], Utah [271,331], and Idaho [305]. It is argued that forage kochia provides mule deer with highly digestible protein that crested wheatgrass lacks; is adapted to very dry sites (5 to 27 inches (127-956 mm) precipitation); is more easily established and has higher growth rates than antelope bitterbrush; is persistent; and is one of the few perennial species that can compete with cheatgrass. It is also suggested that forage kochia can create an open window for the return of native plants by decreasing fire frequency. In a seeding operation on a degraded range in Nevada, managers planted a mixture of forage kochia, Wyoming big sagebrush, fourwing saltbush, and a variety of bunchgrasses. By the 4th growing season, Wyoming big sagebrush, thickspike wheatgrass (*Elymus lanceolatus*), and other native bunchgrasses and forbs were becoming more visible [90]. Care must be taken if using forage kochia, since it can also be invasive.

The practice of seeding nonnative perennial grasses such as crested wheatgrass to contain nonnative annuals, stabilize disturbances, and provide forage for livestock was initially successful, but resulting stands do not provide the structure, functions, resilience, or values of native communities any more than monocultures of cheatgrass [239,253,304]. These plant conversions have negatively impacted wildlife habitat in big sagebrush communities by reducing the diversity of shrubs and forbs that was present in native communities. Big sagebrush communities throughout the western U.S. have seen rapid and continuing declines in populations of small mammals, raptors, sage-grouse, songbirds, other vertebrates, and invertebrates, particularly in the last 20 to 40 years [304]. Monsen and Shaw [304] review the current status of rehabilitation efforts in big sagebrush communities and suggest that failure to establish native species in revegetation plantings is due in part to inexperience and inappropriate planting techniques, and may also be related to species, subspecies, and ecotypes of plants used.

It is commonly thought that restoration of rangeland plant communities using native grasses is difficult [477]. However, natural recovery of some cheatgrass sites by native species has been observed (e.g. [300,456]). Sandberg bluegrass, bottlebrush squirreltail, Thurber needlegrass, western wheatgrass, and thickspike wheatgrass have recolonized and gained dominance on sites once infested by cheatgrass [300]. The natural recovery process certainly suggests that these same species can be effectively used in artificial seedings if seeds are readily available and planting requirements are better understood. Some progress has been made using selected native species to restore cheatgrass-infested sites, and carefully planned seedings in sagebrush benchlands and pinyon-juniper woodlands can often restore the native understory and prevent further spread of cheatgrass. Additional information on the use of native plant materials for sagebrush steppe restoration is given by Jones [221].

As is true for nonnative perennials, establishing native perennials is most effective when cheatgrass is removed or its density substantially reduced [189,303,359,492]. Replacement species for cheatgrass must be able to germinate and produce a vigorous seedling with 1 to 2 days of wet soil, and the seedling must be morphologically adapted to survive drought periods of 10 or more days following a 2-day wet period in order to be competitive with cheatgrass [160]. Hardegree [182] suggests seed priming to increase germination rates of native perennial grasses relative to cheatgrass. Research by Chambers [85] indicates the need to create soil surface features that trap and retain seeds and provide favorable conditions for seedling establishment. Monsen and Shaw [299,301,304] provide detailed discussions of restoration of big sagebrush communities in the Intermountain West using native plants such as big sagebrush, bottlebrush squirreltail, thickspike wheatgrass, and Sandberg bluegrass.

A review by Ott and others [328,329] suggests that native perennial grasses such as bluebunch wheatgrass and bottlebrush squirreltail can have a competitive impact on cheatgrass growth and reproduction, particularly as mature plants. Suppression of cheatgrass invasion following fire has been observed in areas where these grasses or other fire-tolerant native plants were abundant in the prefire community and readily recovered following fire [328,363,456]. Cheatgrass has high relative shoot and root growth rates compared with bottlebrush squirreltail and bluebunch wheatgrass [23]. Detailed treatment of competition between cheatgrass and bluebunch wheatgrass is given by Harris [186]. Bluebunch wheatgrass seedlings may have a better chance of establishing among bottlebrush squirreltail plants than among cheatgrass or medusahead [196].

Bottlebrush squirreltail is a promising candidate for assisting ecological restoration of rangelands dominated by medusahead and cheatgrass [196,220]. It has successfully colonized stands of annual grasses in southern Idaho [23,198], and can establish naturally in rangelands infested by cheatgrass [38,300]. Bottlebrush squirreltail appears particularly well adapted to postfire establishment and competition with cheatgrass [62]. Early fall seeding of bottlebrush squirreltail in cheatgrass-infested rangelands could be effective in future restoration projects [38].

Idaho fescue is a native perennial bunchgrass that can persist in areas with high densities of cheatgrass. Idaho fescue plants from cheatgrass-infested areas tend to be more effective competitors than plants from pristine areas. This suggests that continual competition with cheatgrass selects for a more competitive group of Idaho fescue plants. Hence, seeds from Idaho fescue plants in cheatgrass-infested areas may prove to be more successful at suppressing cheatgrass when planted elsewhere [316,317].

Desert needlegrass (*Achnatherum speciosum*) is a potentially valuable native species for use in restoration seedings in the more arid portions of the Great Basin [359]. Kitchen [233] summarizes information on perennial forb life-history strategies on semiarid rangelands and their implications for revegetation. Meyer [284] discusses establishment of big sagebrush in community restoration projects in the Intermountain West. She suggests 1st establishing early seral species such as bottlebrush squirreltail, since they appear better able to compete with cheatgrass and other annuals, and then seeding big sagebrush along with late-seral understory species. Shaw and Haferkamp [386] discuss using spiny hopsage for revegetation in a Wyoming big sagebrush community in southern Idaho. Belnap and Sharpe [42] present a study using native grasses to revegetate a bunchgrass community in Utah. Winterfat was successfully established after fire in Idaho [303]. Stevens [404] cites evidence and provides guidelines for establishing plants such as big sagebrush, rubber rabbitbrush, fourwing saltbush, antelope bitterbrush, Palmer's penstemon (*Penstemon palmeri*), western yarrow (*Achillea millefolium*), globemallow (*Sphaeralcea*
spp.), and other native and some nonnative species by interseeding into existing stands of cheatgrass.

Jones and others [219] conducted a study to determine if it is possible to restore the moss component of biological soil crusts to a nonnative annual grassland devoid of perennial mosses. Moss recovery or initiation was low over the entire experiment, regardless of the site preparation methods used (sulfometuron methyl, burning, and tilling), all of which were effective for controlling the cheatgrass [219].

In the absence of vesicular-arbuscular mycorrhizae (VAM), mycorrhizal bunchgrasses (e.g. bluebunch wheatgrass and Idaho fescue) are at a competitive disadvantage compared to nonmycorrhizal species (e.g. Russian-thistle) or facultatively mycorrhizal species (e.g. cheatgrass) in capturing limited soil resources. When a plant community is predominantly nonmycorrhizal, VAM fungi decline in abundance and remain depressed until host plants reestablish. Therefore, reestablishment of VAM-dependent plant species may not occur until both plant propagules and the spores of VAM fungi occupy the same site at the same time [405,464]. Rehabilitation of disturbed sites may need to include techniques designed to stimulate the reestablishment of VAM symbiosis [464].

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