55 E. 4th Avenue
Denver, CO 80203
www.quandaryconsultants.com

January 12, 2021

Mr. Jacob Evans
Lead Environmental Specialist
Noble Energy, Inc.
2115 117th Avenue
Greeley, Colorado 80631

**Re: Harper Kona Pipeline**
**Reclamation Workplan**
**NESW Sec 21, T6N, R64W**
**Spill ID 480529**

Dear Mr. Evans,

**Site Background**

On behalf Noble Energy, Inc. (Noble), Quandary Consultants, LLC (Quandary) has prepared a detailed reclamation workplan as an attachment to the Form 27 requesting closure of soil impacts associated with the unintentional release (Remediation Project # 20790) discovered on August 16, 2021, when fluid daylighted from the Harper Kona pipeline. A topographic site location map is presented as Figure 1. An aerial site location map depicting the reclamation area is presented as Figure 2.

As part of the subsequent cleanup by Noble, approximately 10,738 cubic yards of impacted soil was excavated. Confirmation soil samples were collected by Fremont Environmental, Inc. Background soil analysis from adjacent undisturbed land is included in the Form 27. Groundwater was encountered during the excavation at a depth of approximately 14 feet (ft.) below ground surface (bgs). Hydrocarbon impacts were encountered in groundwater within the excavation and continual monitoring will be conducted in accordance with COGCC Rule 913. A National Wetlands Index (NWI) potential wetland is located approximately 475 feet to the southeast of the excavation. The Greeley #2 Canal is approximately 500 ft. to the south of the excavation.

**Soil Suitability Impacts**

Soil analytic results indicate EC levels exceed the COGCC Table 915-1 Soil Suitability for Reclamation allowable level in nine samples ranging from 4.08 millimhos per centimeter (mmhos/cm) to 8.4 mmhos/cm at depths ranging from 3 to 8 ft. bgs. All nine samples are below a background sample of 11.4 mmhos/cm collected at 3 ft. bgs. Five samples indicate that pH levels exceed the Table 915-1 Soil Suitability for Reclamation allowable levels ranging from 8.33 to 8.57 at depths ranging from 0.5 to 4 ft. bgs. All five samples are below 1.25x of a background sample with a pH of 8.32 collected at 8 ft. bgs. One sample indicates a Boron level that exceeds

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the Table 915-1 Soil Suitability for Reclamation allowable level at 3.41 mg/L at a depth of 4 ft. bgs.

**Soil and Vegetation**

The primary soil unit within the excavation area is Thedalund Loam with 1 to 3 percent slopes. Thedalund Loam is comprised of residuum of the weather shale parent geology and some eolian wind deposition. Thedalund soils are used as dry and irrigated cropland, as well as native pastureland. Native vegetation consists of short and tall grass associations consisting of big bluestem, sand bluestem, little bluestem, prairie sandreed, sideoats grama, blue grama, sagebrush, and yucca (NRCS 2008).

The excavated area was on two properties currently owned by Linda L. Herbes and Ben J. Rodriguez. Both landowners were consulted regarding the reclamation of the release area. Prior to the release, the site consisted of dryland pasture. The area was backfilled and approximately 8 inches of new topsoil was brought to the location for reclamation. Both properties have been straw crimped and reseeded. The Herbes property was reseeded with a dryland aggressive native grass mix with smooth brome consisting of 10% Western Wheatgrass, 20% Intermediate Wheatgrass, 10% Canada Wildrye, 20% Slender Wheatgrass, 27% Green Needlegrass, and 13% Smooth Brome. The Rodriguez property was reseeded with a dryland aggressive native grass mix consisting of 10% Western Wheatgrass, 20% Intermediate Wheatgrass, 10% Canada Wildrye, 20% Slender Wheatgrass, and 40 Green Needlegrass. Seed mix tags are attached. Additionally, a review of the United States Forest Service database (attached) indicates the planted seed mixes have a root depth of 1 to 4.9 ft. bgs with Smooth Brome occasionally reaching a depth of up to 9.4 ft. bgs

Stormwater compliance will be met through discing and surface roughening, straw crimping, and seeding and will continue through standard agricultural procedures. Following seeding and initial plant growth, vegetative transects will be conducted to compare plant growth between disturbed and undisturbed areas according COGCC guidance until COGCC reclamation standards are met.

**Conclusion**

Given the typical average taproot depth of dryland pasture in Weld County, Colorado of 1 - 4.9 ft. bgs. and based upon the depth and levels of soil suitability impacts, the risk to vegetation is likely negligible. Based upon this, the depth to groundwater, distance to surface water, and the use of vegetative transects to monitor future growth, Quandary recommends that no further excavation or sampling is necessary.

Please let Mike Dinkel know if you have any questions or require additional information on this reclamation workplan. He can be reached at mdinkel@quandaryconsultants.com or 785-691-7788.

55 E. 4th Avenue
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Sincerely,

Mike Dinkel
Senior Environmental Scientist

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# Figures

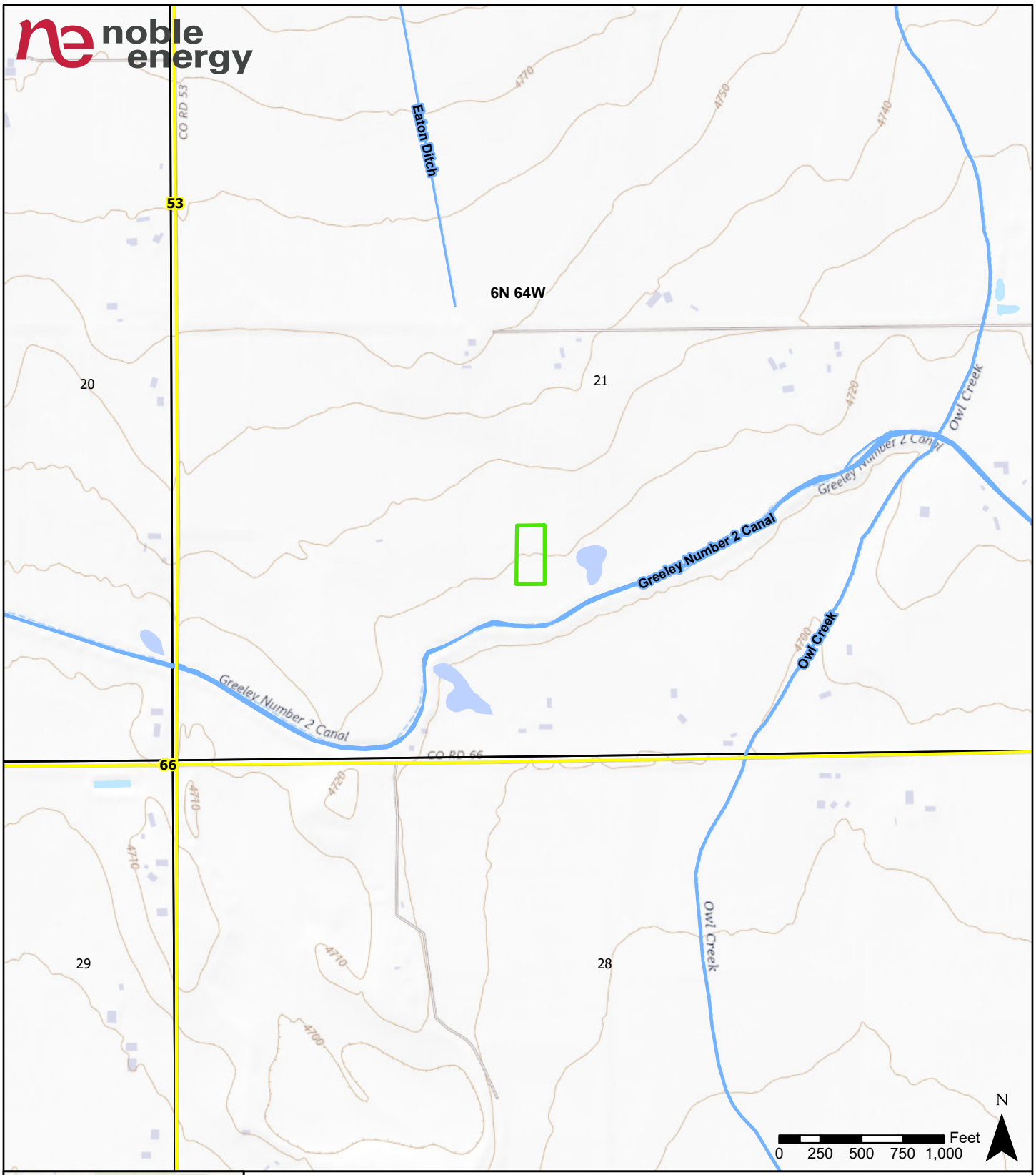



**Figure 1. Harper Kona Pipeline Reclamation Area - Topography**

**Legend**

- Reclamation Area
- Freshwater Emergent Wetland
- Riverine
- CDOT Road
- PLSS Township & Range
- PLSS Section

Client: Noble Energy, Inc.

Author: Clara Jenck Date: 12/06/2021

NESW & SESW, Sec. 21, T6N, T64W

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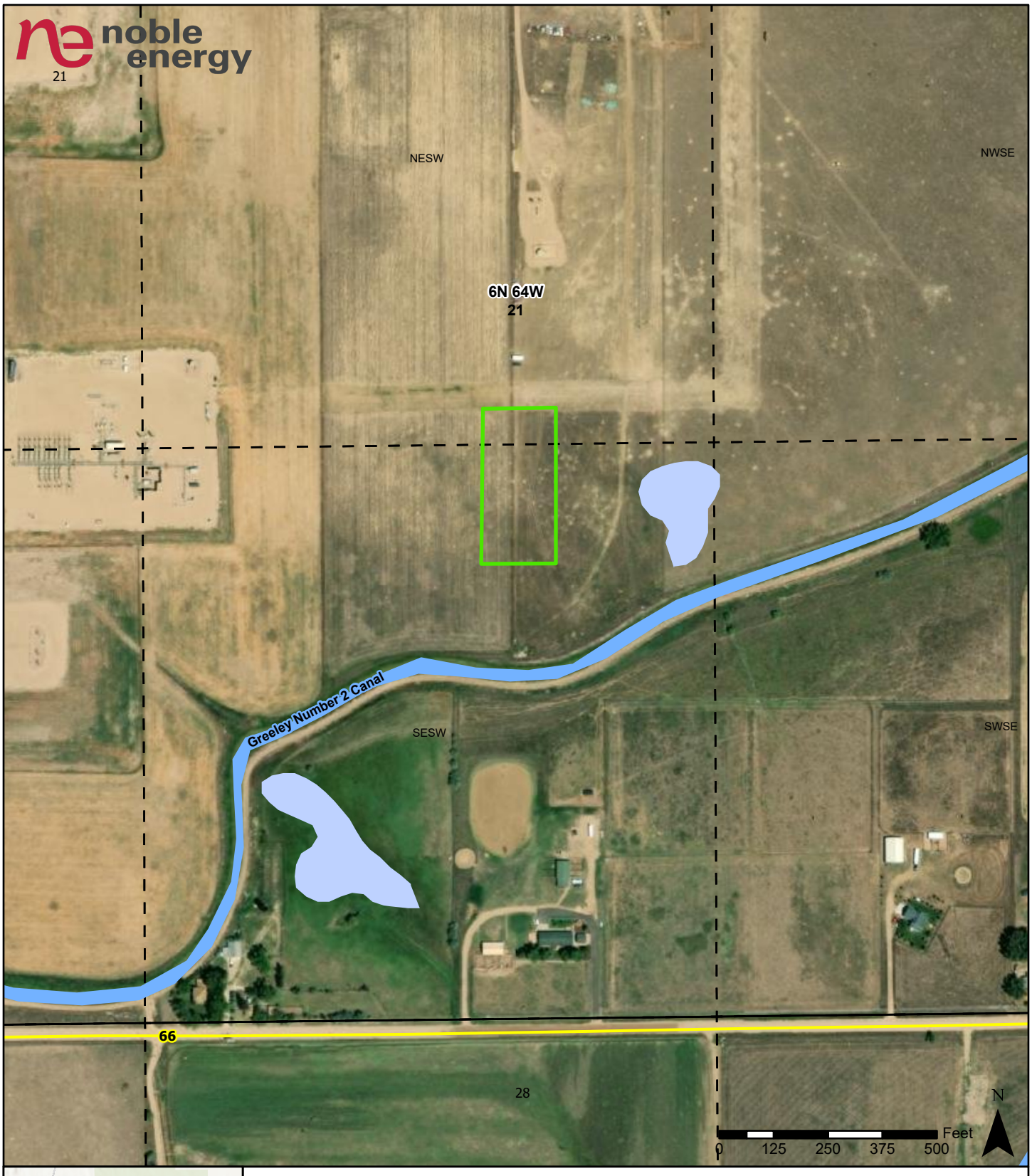



**Figure 2. Harper Kona Pipeline Reclamation Area - Aerial Imagery**

**Legend**

- Reclamation Area
- Freshwater Emergent Wetland
- Canal
- CDOT Road
- PLSS Township & Range
- PLSS Section
- PLSS Qtr/Qtr

Client: Noble Energy, Inc.

Author: Clara Jenck Date: 12/06/2021

NESW & SESW, Sec. 21, T6N, T64W

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## LEGEND

- RELEASE POINT
- SOIL SAMPLE LOCATION
- AST — ABOVE GROUND STORAGE TANK
- FORMER — FORMER FACILITY
- CONTAINMENT BERM
- EXTENT OF EXCAVATION
- FENCE LINE
- 12" OIL PRODUCED WATER PIPELINE
- 16" PIPELINE

| | |
|---|---|
| 08/19/2021 | DATE SAMPLED |
| B - W Wall ~ 0.5' | SAMPLE ID & DEPTH (ft) |
| pH 8.33 | pH (pH units) |

| | |
|---|---|
| 08/19/2021 | DATE SAMPLED |
| B - Floor ~ 3' | SAMPLE ID & DEPTH (ft) |
| EC 4.88 | EC (mmhos/cm) |

| | |
|---|---|
| 08/26/2021 | DATE SAMPLED |
| L0 - Floor ~ 4' | SAMPLE ID & DEPTH (ft) |
| B 3.41 | BORON (mg/L) |

| | |
|---|---|
| 08/26/2021 | DATE SAMPLED |
| L0 - Floor ~ 4' | SAMPLE ID & DEPTH (ft) |
| pH 8.57 | pH (pH units) |
| B 3.41 | BORON (mg/L) |

N

0 20 40 60 80 100
Scale (feet)

Figure 3
**INORGANIC EXCEEDANCES SOIL CHEMISTRY MAP**

**NOBLE MIDSTREAM, INC.**
**Harper Pipeline Release**
NESW Sec. 21, T6N, R64W, 6th PM
Weld County, Colorado

| | | | |
|---|---|---|---|
| Project No. **CO21-074** | Prepared by | Drawn by **TA** | FREMONT ENVIRONMENTAL |
| Date **12/17/21** | Reviewed by **PH** | Filename **21074QFFINORG** | |

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## Attachments

Pawnee Buttes Seed Inc.

P.O. Box 100, 2438 7th Avenue
Greeley, CO 80632
970-356-7002, 1-800-782-5947, 970-356-7263 fax
Email: info@PawneeButtesSeed.com
www.PawneeButtesSeed.com

***** SEED QUOTE *****

***** ALL PRICES FOB GREELEY *****

Customer: Daviscapes
Date: October 22, 2021
Contact:
Phone:
Address:
Fax:
City, State, Zip:

Acres:
Job Name: PBSI Dryland Aggressive #1
Seeding Rate/Acre:

| Kind | % Mix | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Western Wheatgrass | 10.00 | | | | | | | |
| Intermediate Wheatgrass | 20.00 | | | | | | | |
| Canada Wildrye | 10.00 | | | | | | | |
| Slender Wheatgrass | 20.00 | | | | | | | |
| Green Needlegrass | 40.00 | | | | | | | |
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Totals 100.00

**Sales Staff: Andrew Dickinson**

Pawnee Buttes Seed Inc.

P.O. Box 100, 2438 7th Avenue
Greeley, CO 80632
970-356-7002, 1-800-782-5947, 970-356-7263 fax
Email: info@PawneeButtesSeed.com
www.PawneeButtesSeed.com

***** SEED QUOTE *****

***** ALL PRICES FOB GREELEY *****

Customer: Daviscapes
Contact: Darby Davis
Address:
City, State, Zip:

Date: October 19, 2021
Phone:
Fax:

Acres: 20
Seeding Rate/Acre: 25

Job Name: Dryland Aggressive with Smooth Brome

| Kind | % Mix | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Western Wheatgrass | 10.00 | | | | | | | |
| Intermediate Wheatgrass | 20.00 | | | | | | | |
| Canada Wildrye | 10.00 | | | | | | | |
| Slender Whaetgrass | 20.00 | | | | | | | |
| Green Needlegrass | 27.00 | | | | | | | |
| Smooth Brome | 13.00 | | | | | | | |
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Totals 100.00

**Sales Staff: Andrew Dickinson**

# BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Elymus canadensis



GENERAL BOTANICAL CHARACTERISTICS:
Canada wildrye is a cool season [5,6,7,13], drought intolerant [27], perennial bunchgrass [5,62,97] native to North America [6]. It is a tall, coarse [62,81], robust grass, attaining heights of 2 to 5 feet (0.6-1.5 m) [50,93]. Culms are hollow [39] with stems becoming tough and woody at maturity [50]. Leaf blades are broad, flat, and rough, usually 6 to 12 inches (15-30 cm) long [49] and 0.5 inches (1.2 cm) or more wide [49,62]. The inflorescence is a spike [47,49] generally 6 inches (15 cm) tall with sharp awns [49].

Canada wildrye is a rhizomatous species [39,64] however, rhizomes are rare and generally less than 1.6 inches (4 cm) long and 0.04 to 0.08 inches (1-2 mm) in diameter [39]. Roots are noncoarse [1] and fibrous [5,21] forming a wide fine branching network [67].

Observations of Canada wildrye root system within a true prairie lowland show a shallow, wide-spreading root system that may exceed 2 feet (0.6 m) on all sides. Roots are fine 0.02 inches (0.5 mm) or less in diameter, highly branched, tough and wiry. Roots are usually found within the 1st 2.5 feet (0.76 m) of soil [94].

Canada wildrye is a facultative mycotroph [24,43,67] with a mycorrhizal dependency of 25% in prairie soil [43].

RAUNKIAER [71] LIFE FORM:
Hemicryptophyte

REGENERATION PROCESSES:
Canada wildrye may reproduce through seed or vegetative production. However, it does not rely heavily on vegetative reproduction [86,96]. Canada wildrye produces a high ratio of reproductive to vegetative stems [31] and persistence is generally maintained through production of seed [96].

Seed:
Canada wildrye may outcross [36,76] or self-fertilize [6,36,76]. Sanders and Hamrick [76] found Canada wildrye most often self-fertilizes throughout the northern Great Plains with outcrossing rates varying between populations. Gable [36] observed a much greater outcrossing percentage than that of self-fertilization.

Throughout its distribution, Canada wildrye seed usually matures in the early fall [21]. In the southern portion of its' range, Canada wildrye seed most often mature in July with northern populations maturing in August [98]. Seed yields can average 300 to 400 lbs. (136-181 kg) per acre from native stands [49]. There is no report on seed dispersal mechanisms. However, the presence of long awns suggests the potential for long distance dispersal by animals.

Canada wildrye seeds are highly germinable, showing the best germination in soils with high water content [13]. Seedlings are vigorous [49,98] and usually establish quickly [98]. Robocker and others [74] found Canada wildrye seeds required an average of 8 days before emergence. Seeds were planted in flats at 0.125 to 0.25 inch (0.318-0.64 cm) depths containing a mixture of 1/2 sand and 1/2 Miami silt loam topsoil and germinated in greenhouse conditions at 60 to 65 degrees Fahrenheit (16-18 °C). Average emergence was 54.7%.

Vegetative:
Rhizomes are very short and tend toward vertical rather than horizontal orientation. Mueller [64] found an average rhizome length of 1 inch (2.5 cm), usually occurring in the upper 1.5 inches (3.8 cm) of soil. Rhizomes are more pronounced in loose sandy soil compared to loams. Rhizomes are generally longer in sandy soils compared to loams and may occur as deep as 5 inches (12.7 cm). Observations were made in east-central Nebraska, where average radial increase of Canada wildrye was 2 inches (5.1 cm) per year in loam and approximately 1.5 inches (3.8 cm) in sand.

SITE CHARACTERISTICS:
Canada wildrye is most often associated with mesic environments [21,81,86], inhabiting prairies, streambanks, lakeshores, ditches, and various disturbed sites [39] such as road ditches and other areas of disturbed open ground [36,81,86]. In general Canada wildrye prefers mesic, lowland soils [1].

Soils:
Canada wildrye is adapted to a wide variety of soils [5,21,39,98]. It may inhabit gravelly [39], sandy, silty, or clayey soils [5] and areas of relatively low soil fertility [21] especially the soil nutrient phosphorous [67].

Regional:
Canada wildrye prefers prairie lowlands of Iowa [31], Kansas [38], and Nebraska [81,86]. In North Dakota, Canada wildrye is most often found in moist ravines and streambanks [50]. In sandhill regions of North Dakota, Canada wildrye occurs on disturbed uplands most often around animal burrows and rim areas of sand blowouts [18]. Canada wildrye is commonly found along roadsides adjacent to croplands, pastures, and woodlands in southeastern Iowa [15].

Populations are sparse in the west. In Utah Canada wildrye is found along waterways and in wet, sometimes saline meadows [97]. It is confined to moist ravines and streambanks in eastern Montana, but is widespread in moist mountain valleys of western Montana at medium and low altitudes [62]. Canada wild rye is most often found on disturbed areas in California [47].

SUCCESSIONAL STATUS:
Canada wildrye is generally an early seral species [27,59,80], increasing with disturbance. In Wisconsin prairies, regular disturbance from annual floods maintains Canada wildrye as an early seral dominant [17]. Canada wildrye is a pioneer species along many roadsides in Montana [7].

In sandhills of southeastern North Dakota, Canada wildrye is considered a mid-seral species [18].

SEASONAL DEVELOPMENT:
Canada wildrye growing points appear early in the growing season [31]. Lateral roots of seedlings form early and branch widely. Overall growth of foliage is slow compared to root growth [13]. Canada wildrye may show summer dormancy during periods of drought, resuming growth in the fall under adequate moisture [88].

In mesic tallgrass prairies of Nebraska, Canada wildrye vegetative growth usually begins in late April, flowering in mid-July with seeds maturing in August [86]. Seedlings may survive through winter resuming active growth in the spring [13].

Neiland and Curtis [65] observed Canada wildrye phenology in Madison, Wisconsin. Stem elongation began the middle of May, continuing to the end of June, after which anthesis began and continued until the middle of August. Production of crown roots was observed from February until the end of May, occurring again in August. Secondary and tertiary root growth was found to occur from February until the middle of June and again from the beginning of August until the beginning of October.

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# FIRE ECOLOGY

SPECIES: Elymus canadensis

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FIRE ECOLOGY OR ADAPTATIONS:
Although a perennial species, Canada wildrye persistence is dependent upon rapid reproduction through seed rather than length of life of the individual [96]. Postfire establishment occurs primarily through seed with vegetative production of the root crown to a lesser extent [35].

FIRE REGIMES:
Fire regimes for plant communities and ecosystems in which Canada wildrye occurs are summarized below. Find further fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

| Community or Ecosystem | Dominant Species | Fire Return Interval Range (years) |
|---|---|---|
| bluestem prairie | *Andropogon gerardii* var. *gerardii-Schizachyrium scoparium* | < 10 [56,69] |
| Nebraska sandhills prairie | *A. g.* var. *paucipilus-S. s.* | < 10 |
| bluestem-Sacahuista prairie | *Andropogon littoralis-Spartina spartinae* | < 10 |
| sagebrush steppe | *Artemisia tridentata/Pseudoroegneria spicata* | 20-70 |
| 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. g.-Buchloe dactyloides* | < 35 [69] |
| sugarberry-America elm-green ash | *Celtis laevigata-Ulmus americana-Fraxinus pennsylvanica* | < 35 to 200 [91] |
| wheatgrass plains grasslands | *Pascopyrum smithii* | < 35 [69] |
| Great Lakes spruce-fir | *Picea-Abies* spp. | 35 to > 200 |
| northeastern spruce-fir | *Picea-Abies* spp. | 35-200 [26] |
| Rocky Mountain ponderosa pine* | *Pinus ponderosa* var. *scopulorum* | 2-10 |
| Arizona pine | *P.* var. *arizonica* | 2-10 [4] |
| Table Mountain pine | *P. pungens* | < 35 to 200 [91] |
| red pine (Great Lakes region) | *P. resinosa* | 10-200 (10**) [26] |
| eastern cottonwood | *Populus deltoides* | < 35 to 200 [69] |
| mountain grasslands | *Pseudoroegneria spicata* | 3-40 (10**) [3,4] |
| California oakwoods | *Quercus* spp. | < 35 [4] |
| oak-hickory | *Quercus-Carya* spp. | < 35[91] |
| oak savanna | *Q. macrocarpa/Andropogon gerardii-Schizachyrium scoparium* | 2-14 [69,91] |
| little bluestem-grama prairie | *Schizachyrium scoparium-Bouteloua* spp. | < 35 [69] |
| elm-ash-cottonwood | *Ulmus-Fraxinus-Populus* spp. | < 35 to 200 [26,91] |

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

POSTFIRE REGENERATION STRATEGY [4]:
Rhizomatous herb, rhizome in soil
Tussock graminoid
Secondary colonizer (on-site or off-site seed sources)

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# FIRE EFFECTS

SPECIES: Elymus canadensis

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IMMEDIATE FIRE EFFECT ON PLANT:
Canada wildrye is usually top-killed by fire. The coarse stems and leaves of Canada wildrye make it less prone to prolonged burning [99,100]. Little heat is transferred to crown and basal buds located just below the ground surface [74].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
No entry

PLANT RESPONSE TO FIRE:
Canada wildrye responds poorly to early spring fire [74]. The best postburn response comes from summer fire [51,63]. Postfire establishment occurs primarily through seed [35].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Howe [51] evaluated postburn response of Canada wildrye within a tallgrass prairie of south-west Wisconsin. Canada wildrye decreased in relation to warm season associates, when subjected to early spring burn (late March) or left unburned. A decrease in Canada wildrye also occurred following mid-summer fire (15 July). However, a greater persistence of Canada wildrye was observed in mid-summer burned areas versus unburned controls. Details of this study and others by Howe are described in the research project summary, Herbaceous responses to seasonal burning in experimental tallgrass prairie plots.

In Wyoming and Utah, green needlegrass is found with Wyoming big sagebrush, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), basin big sagebrush (*A. t.* ssp. *tridentata*), antelope bitterbrush [56,77], shrubby cinquefoil, and common juniper (*Juniperus communis*) [105]. It is a codominant of western wheatgrass and spike fescue (*Leucopoa kingii*) [15]. Green needlegrass is also associated with Sandberg bluegrass [56], needle-and-thread grass, cheatgrass, Indian ricegrass [77], and sedges [56].

In Colorado and Nebraska, green needlegrass is found in the understory of interior ponderosa pine with blue grama, cheatgrass, Kentucky bluegrass, needle-and-thread grass, western wheatgrass, little bluestem, sideoats grama, prairie sandreed, plains muhly, prairie Junegrass, Japanese brome, threadleaf sedge, sun sedge, dandelions (*Taraxacum* spp.), common juniper, wax currant (*Ribes cereum*), fringed sage, and common snowberry (*Symphoricarpos albus*) [82,132].

In Alberta, green needlegrass occurs in the wheatgrass-bluegrass (*Agropyron* spp.-*Poa* spp.) community, reedgrass-wheatgrass (*Calamagrostis* spp.-*Agropyron* spp.) community [117], and rough fescue (*Festuca altaica*) association [73]. In Saskatchewan, Manitoba, and Alberta, green needlegrass is codominant with western wheatgrass, needle-and-thread grass, blue grama, and buffalo grass [5,10,83,91,103,151]. It is associated with Sandberg bluegrass, plains muhly, threadleaf sedge [5], prairie Junegrass [5,83,151], western wheatgrass [5,103] plains reedgrass, sun sedge, obtuse sedge (*Carex obtusata*) [83,151], timber oatgrass (*Danthonia intermedia*), Idaho fescue, porcupine grass [73,83,151], needleleaf sedge, [83,151], Pumpelly brome (*Bromus pumpellianus*), and pinegrass (*Calamagrostis rubescens*) [73]. Green needlegrass is associated with the shrubs fringed sagebrush [5,83,151], plains silver sagebrush, and Gardner's saltbush, winterfat (*Krascheninnikovia lanata*) [5]. It is also found with little clubmoss (*Selaginella densa*), prairie goldenrod (*Solidago missouriensis*), pussytoes, and plains prickly-pear [5].

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# BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Nassella viridula

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GENERAL BOTANICAL CHARACTERISTICS:
Green needlegrass is a tufted, perennial, native, long-lived, cool-season bunchgrass [1,8,14,18,20,24,28,29,35,42,47,65,74,94,99,101,126,128]. At maturity, the plants are 12 to 48 inches (30-122 cm) tall [4,49,51,61,72,86,97,107,109,127,128,139,141]. It has "good" drought tolerance [33,43,109,127], is moderately tolerant of flooding [57] and short-term submergence [139], and is capable of vigorous seedling growth [78]. Green needlegrass has a weak tolerance to shade from scattered shrubs and woodland openings and is very winter hardy [139].

The numerous, mostly basal leaves, are flat to involute and taper to threadlike tips [139]. Average length of leaves ranges from 4 to 12 inches (10.2-30.5 cm) [127]. Inflorescences are narrow, loose spikelets and 4 to 8 inches (10-20 cm) [61,97] long. Awns are bent twice and are 0.75 to 1.5 inches (1.9-3.8 cm) long [51,61,72,97,141]. Old sheath bases are often persistent [141].

Green needlegrass has a deep, up to 4 to 5 feet (122-152 cm) [140], fibrous root system [4,22,88,127,139], similar to needle-and-thread grass. The main roots are 0.04 inch (1 mm) in diameter; lateral spread is 14 inches (35.6 cm) in the first 6 inches (15.2 cm) of soil, and 18 inches (45.7 cm) in the first 12 inches (30.5 cm). The system is well branched and rootlets are abundant to depths of 2.5 feet (76.2 cm) [140].

RAUNKIAER LIFE FORM [108]:
Hemicryptophyte

REGENERATION PROCESSES:
Green needlegrass reproduces from seed and through tillering [94,97]. New seeds of green needlegrass have a higher occurrence of dormancy and a lower germination rate than mature seeds. Stratification in moist sand was found to be the best treatment to break dormancy. Fall plantings are successful because overwintering in soil can break the dormancy [113].

SITE CHARACTERISTICS:
Green needlegrass is found on foothills, open hillsides and parks, in mountain meadows, canyons, and open woodlands [51,57,61]. It is a pioneer on abandoned croplands and coarse textured disturbed sites [139]. Green needlegrass is generally found in semi-arid, continental climates in a wide range of elevations [7,32,47]. Elevational ranges for green needlegrass are as follows:

| | | |
|---|---|---|
| SD | 358 to 3,000 feet (109-900 m) | [64,87,90,112] |
| MT | 2,200 to 9,000 feet (671-2,700 m) | [12,34,57,92,102,122] |
| AB | 3,000 to 3,200 feet (914-975 m) | [20] |
| ND | 1,500 to 2,013 feet (460-610m) | [17,31,109] |
| SK | 2,247 feet (685 m) | [83] |
| WY | 7,600 to 9,000 feet (2,280-2,700 m) | [56,57] |

Green needlegrass is found in a wide range of temperatures. Mean annual temperatures where green needlegrass is present are 3.4 to 117 degrees Fahrenheit (-15.9 to 47 $^{o}$C). Green needlegrass occurs in areas with an average precipitation of 10-26 inches (254-660 mm) and the majority of the precipitation occurs between April and September [5,9,11,20,124,134,148]. Mean annual precipitation ranges for green needlegrass are as follows:

| | | |
|---|---|---|
| ND | 14 to 17.1 inches (356-438 mm) | [11,17,31,32,40,50,55,98,109] |
| SD | 14.7 to 38.6 inches (374-980 mm) | [9,35,46,74,87,90,100,112,116,144] |
| AB | 10.7 to 12.8 inches (272-326 mm) | [20,103] |
| MT | 6.74 to 23.14 inches (171-587.8 mm) | [12,34,37,66,92,93,102,106,122,131] |
| SK | 12.9 to 13.28 inches (327-337 mm) | [67,83] |
| WY | 10 to 14 inches (254-356 mm) | [56] |

Soils: Green needlegrass is found on a variety of soil types [4,9,31,35,47,48,50,82,83,87,102,109,110,123,144,151]. It is tolerant of heavy clay soils, is less common on loams and sandy soils [90,127], and is weakly to moderately tolerant of soil salinity [139].

SUCCESSIONAL STATUS:
In North Dakota, green needlegrass is considered a major species of the climax vegetation with western wheatgrass, blue grama, needle-and-thread grass, and threadleaf sedge [58]. It is considered a major climax grass, dominant with western wheatgrass [100]. Green needlegrass is an early seral species on disturbed sites [94].

SEASONAL DEVELOPMENT:
Green needlegrass is one of the first in its association to start spring growth in the western Northern Great Plains [57]. It generally starts growth in March, grows vegetatively in May and June, heads out in June, and matures in July [4,22,96,127,139].

Goetz [49] observed these dates of development in North Dakota during 1955-1962:

| | |
|---|---|
| initiation of fruiting stalk | May 26 |
| head emergence | June 12 |
| anthesis | June 16 |
| seeds mature | July 2 |
| seeds starting to shed | July 12 |

White and Wight [145] observed these dates of development in Montana during 1975 and 1976:

| | 1975 | 1976 |
|---|---|---|
| late boot | June 7 | May 21 |
| first inflorescence | June 10 | May 24 |
| anthesis | June 23 | June 7 |
| start of dissemination | July 14 | June 21 |

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# FIRE ECOLOGY

SPECIES: Nassella viridula

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FIRE ECOLOGY OR ADAPTATIONS:
Effect of fire on green needlegrass depends on season of burn and site characteristics [144]. Depending on the phenological state of the plant, green needlegrass increases or decreases following fire [79,144]. Aboveground vegetation of green needlegrass is usually consumed by fire, but individual culms may survive [35]. Regeneration is through seed and tillering [143]. The effects of fire, increases in growth or decreases in vigor, can be immediate and last up to 3 years following the fire [32,39,80,102,104,141].

FIRE REGIMES:
Fire return intervals for plant communities and ecosystems in which green needlegrass occurs are summarized below. Find further fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

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

stands. Other insect pests of crested wheatgrass are leafhoppers, grubs, and mature click beetles and billbugs [53].

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# BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Agropyron cristatum

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GENERAL BOTANICAL CHARACTERISTICS:

Crested wheatgrass is a cool-season, medium-height, exotic perennial bunchgrass. The plant is drought- and cold-resistant and long-lived, enabling it to establish in recognizable monocultures [105]. Crested wheatgrass culms are 10 to 40 inches (25-100 cm) tall [30] and widely spaced. The deep, finely branched fibrous roots of crested wheatgrass penetrate to a maximum depth of 8 feet (2.4 m), with most roots extending to a depth of 3.3 feet (1 m) [80]. Crested wheatgrass is common in the Northern Great Plains and in Canada [105], while desert wheatgrass is more common throughout the western United States. Desert wheatgrass is tall and coarse, while crested wheatgrass is smaller, leafier, and has broader seedheads. Crested wheatgrass is a diploid species, which differentiates it genetically from desert wheatgrass, a tetraploid [34].

Crested wheatgrass remains productive for more than 30 years. Stand mortality is virtually unknown, except in cases of extreme drought during critical phenological stages [51].

RAUNKIAER LIFE FORM:

Hemicryptophyte

REGENERATION PROCESSES:

Crested wheatgrass reproduces by seed or vegetatively and is self-sterile [35]. Crested wheatgrass seedlings are very hardy, vigorous, and easily established [67]. The seeds of crested wheatgrass germinate well throughout a range of temperatures [7], allowing the plant to spread rapidly [62]. Crested wheatgrass produces tillers, and its ability to spread vegetatively contributes to its presence at higher elevations, where the growing season may not be long enough each year to produce seed [51]. However, in drier habitats, the ability of rhizomatous native grasses to propagate without setting seed allows them to compete well with crested wheatgrass [85]. Crested wheatgrass is able to emerge from a relatively deep soil depth, which allows it to escape the more extreme environmental soil conditions closer to the surface. Crested wheatgrass shoots have long, numerous, and quick-growing roots, which may explain strong seedling establishment [67].

SITE CHARACTERISTICS:

Crested wheatgrass is tolerant of very cold and very dry conditions, typical of both its native habitat in Russia and some areas of the northern Great Plains [12,24, 66,103]. It grows best on medium-textured soils, from sandy loams to clay loams. Crested wheatgrass does not grow well in loose sandy soils, heavy clays, or saline soils [84,91]. Crusted soils impede crested wheatgrass seedling emergence [67].

Crested wheatgrass thrives at around 12 to 16 inches (305-406 mm) of precipitation and competes poorly with other grasses on moister sites [24,63,105]. In Utah, crested wheatgrass appears on sites with precipitation of at

least 12 inches (300 mm) [115].

Crested wheatgrass appears in the following elevations:

| State | Elevation, in feet (m) |
|---|---|
| WY | above 6,000 (1800) [13] |
| UT | 2,730 to 9,040 (910-2740) [115] |
| CA | 1,900 to 5,000 (600-1500) [54] |
| CO | 5,000 (1,500) [52] |

Crested wheatgrass is more competitive on mesic sites than desert wheatgrass, and desert wheatgrass competes better on more xeric sites than crested wheatgrass [38].

SUCCESSIONAL STATUS:

Due to the broad range of habitat types in which crested wheatgrass has been planted, reports conflict on the plant's persistence. Crested wheatgrass is persistent and allows little establishment of native species in some habitat types, especially in arid and heavily grazed areas [2]. A crested wheatgrass community in southeastern Alberta was determined to be over 40 years old, and in central North Dakota, northern Arizona, and southern Idaho, stands over 30 years old have been identified [68].

However, shrub re-invasion of crested wheatgrass occurs in the Intermountain West, especially in wet years. Unkilled mature sagebrush in the seeded area is a source of reinvasion [87]. In the arid shadscale (*Atriplex* spp.) zone of Utah and Nevada, stands of crested wheatgrass appear to be shorter lived, with an estimated 10-year life span [18]. Anderson and Marlette [4] point out that the age of these stands may reflect the available data, and not the potential for stand longevity. They suggest that crested wheatgrass may inhibit or preclude the re-establishment of native species on disturbed sites and may become the dominant species.

In laboratory trials, volatile substances and aqueous extracts from the leaves of big sagebrush exhibited allelopathic, inhibitory effects on germination and shoot and radicle growth of crested wheatgrass seedlings [50]. However, simultaneous establishment of both sagebrush and crested wheatgrass favors the grass [17].

Crested wheatgrass has limited ability to invade undisturbed shortgrass communities in northeastern Colorado and was an unimportant component in the recovery, after 53 years, of old fields [28].

SEASONAL DEVELOPMENT:

Crested wheatgrass greens up 2 to 4 weeks earlier than native bunchgrass species. It goes dormant in the summer, but if soil moisture is available, it will grow again in the fall. In Alberta, at the northern end of the plant's range, seasonal development was as follows [85]:

| stage of maturity | sample date |
|---|---|
| preflower | 5/10 |
| heading | 6/8 |
| flowering | 6/29 |
| seed ripe | 7/30 |
| seed shed | 10/21 |

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# FIRE ECOLOGY

SPECIES: Agropyron cristatum

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FIRE ECOLOGY OR ADAPTATIONS:

Crested wheatgrass burns quickly and is therefore less susceptible to fire damage than some bunchgrass species [32]. In especially thick bunchgrasses, the fire may stay longer in the culms, resulting in heat transfer to the ground and the death of the plant. In crested wheatgrass, there is usually little heat transfer into the soil, so the tillers and root system are usually undamaged [107].

POSTFIRE REGENERATION STRATEGY:

Tussock graminoid

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# FIRE EFFECTS

SPECIES: Agropyron cristatum

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IMMEDIATE FIRE EFFECT ON PLANT:

Fire usually burns crested wheatgrass aboveground but underground parts survive [79].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:

No entry

PLANT RESPONSE TO FIRE:

Researchers characterize crested wheatgrass as "slightly damaged" [97] or "undamaged" by prescribed fire [93,119], since coarse stems and sparse leafy parts inhibit heat transfer down into the culms or soil. Young [119] says postfire recovery is rapid.

Crested wheatgrass in eastern Idaho and western Wyoming occurs in low flammability growth habitats, and its deep underground tillers help it to survive fire. Crested wheatgrass growth may be favored by late summer fire, but spring fire can decrease yields for several years [21].

Crested wheatgrass can be used as a "greenstrip" or fuelbreak in semi-arid rangelands to help control wildfire [49]. It is moderately flammable, produces moderate litter, has an extensive range, competes well, and is a good sprouter. A mature stand of crested wheatgrass can help control annual grassland fires like those found in sites now invaded by cheatgrass throughout the arid West, particularly in sagebrush-steppe habitats [90,94].

A study at Experimental Farm, Swift Current, Saskatchewan, investigated the effects of spring and fall burns on crested wheatgrass pastures. The spring burn occurred while the grass was growing vigorously, and forage yield and domestic sheep consumption on the pasture were reduced for the following 2 years. The grass was dormant during the fall burn, which took place during November. Although forage yield was reduced in the following year, sheep consumption was not. Lodge [79] concluded the fall burning of crested wheatgrass reinvigorated the stand.

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:

Slender wheatgrass is used for rehabilitating alpine meadows and other high elevation habitats [9]. Cultivars are not recommended for this use; seed must be collected from alpine sites in late summer or early fall. Fall plantings yield higher rate of germination at high elevation than do spring plantings. Surface mulching is recommended [8].

Slender wheatgrass has been used in a variety of watershed projects, including reclaiming logged-over watershed areas, improvement of subalpine watershed, and streambank and streambottom improvement [30,48,60]. A watershed rehabilitation project in New Mexico increased available water run-off by 40 percent following seeding with slender wheatgrass and other grasses [13].

Slender wheatgrass is planted using a seed mix selected for the particular rehabilitative purpose. The mix consists of other grasses, and may contain forb seed as well. Possible companion seeds are too numerous to list. A selected few which have been used successfully include western wheatgrass (Pascopyrum smithii), intermediate wheatgrass (Thinopyrum intermedium), blue wildrye (Elymus glaucus spp. glaucus), tall oatgrass (Arrhenatherum elatius), and Parry clover (Trifolium parryi). Slender wheatgrass seedlings have also been successfully transplanted onto disturbed sites [11].

Heavy metal and hydrocarbon tolerances: Slender wheatgrass does well in soils containing high levels of boron (10-20 p/m). Some research suggests that this species tolerates heavy and lead bitumen-contaminated soils. It did not establish well, however, on alkaline tailings in Quebec that were contaminated by unidentified heavy metals [23].

**OTHER USES AND VALUES :**
Slender wheatgrass is cultivated on haylands of the northern Great Plains [55].

**OTHER MANAGEMENT CONSIDERATIONS :**
Range: Slender wheatgrass will maintain vigor indefinitely under moderate grazing [47]. It is a decreaser on overgrazed cattle ranges because its short rootstocks cannot withstand heavy grazing as well as species with well-developed rhizomes [25,59]. Ellison [17] reported slender wheatgrass as scarce on overgrazed cattle ranges of the Wasatch Plateau, Utah, but plentiful in areas inaccessible to livestock. Slender wheatgrass has increased on some mountain ranges following heavy use by sheep, however, because sheep will only lightly graze the leaves of coarser ecotypes [7]. Slender wheatgrass cover at five different levels of livestock grazing in Riding Mountain National Park, Manitoba was as follows [53]:

| | Mean Foliage Cover (%) |
|---|---|
| slight use | 11.0 |
| light use | 8.7 |
| moderate use | 16.9 |
| heavy use | 28.5 |
| severe use | 2.0 |

Slender wheatgrass populations decrease when livestock are allowed to graze during flowering and seed set [42].

Slender wheatgrass has been used to inhibit the highly unpalatable Rocky Mountain iris (Iris missouriensis) on ranges overtaken by the iris [16].

## BOTANICAL AND ECOLOGICAL CHARACTERISTICS

## SPECIES: Elymus trachycaulus

**GENERAL BOTANICAL CHARACTERISTICS :**
Slender wheatgrass is a perennial, cool-season, short-lived, coarse, tufted bunchgrass. Leaves are from 3 to 13 inches (8-33 cm) long and 0.25 to 0.5 inch (0.6-1.3 cm) wide, with basal leaves longer than upper leaves. The culms are erect, ranging from 6 to 48 inches (8-120 cm) in height, and bear terminal, erect spikes [37,55]. The root system is dense, consisting of coarse and fine fibrous roots which extend beyond 12 inches (30 cm) in depth. One author has reported this species as having short rhizomes [23]. The dense root system makes this species moderately drought tolerant [44].

**RAUNKIAER LIFE FORM :**
Chamaephyte

**REGENERATION PROCESSES :**
Sexual: Slender wheatgrass is a self-pollinated or wind-pollinated species with heavy seed production [5,20,23]. Seed is disseminated by transport on animal hides. The seed, stored in seed banks, remains viable for 3 to 6 years, with a germination capacity of 80 to 90 percent. This species requires 1- to 2-month short night/long day stratification prior to germination. The temperature and light regime required for optimal germination fluctuates from a daily minimum of 59 degrees Fahrenheit (15 deg C) for 16 hours without light to a maximum of 77 degrees (25 deg C) for 8 hours with light [20,42]. Slender wheatgrass requires a moderately moist bare mineral or lightly mulched seedbed. It is a good competitor on disturbed sites for the first 2 to 3 years. Seedling establishment is often poor in older communities because seedlings to not grow well in thatch or other heavy litter [40]. Generally, seed dispersal and seedling establishment is the primary method of reproduction in this species [23]. Considerable variation, however, has been noted among northern ecotypes in both seed production and vegetative reproduction.

Vegetative: Slender wheatgrass reproduces asexually by tillering [23].

**SITE CHARACTERISTICS :**
Widely distributed, slender wheatgrass has numerous ecotypes that occur in widely differing climates. Slender wheatgrass is found on semiarid ranges, in temperate and boreal forests, and in subalpine, alpine, and subarctic habitats [8,23]. More detailed site characteristics are as follows:

Soil: Slender wheatgrass grows in dry to moist, medium-textured soil. It tolerates silt and clay but does best on sandy loam. This species has a high salt tolerance. Soil pH usually ranges from moderately acid to moderately alkaline, although it has been reported growing in soils with a pH as high as 8.8 [20,23].

Precipitation: Slender wheatgrass requires from 10 to 20 inches (25 - 50 cm) of annual precipitation [20].

Elevation: The following ranges in elevation have been reported for slender wheatgrass in several western states [24,25,38]:

AZ: 5,000-12,000 ft (1,370-3,660 m)
CA: below 11,000 ft (3,330 m)
CO: 4,500-12,000 ft (1,370-3,600 m)
UT: 4,500-12,200 ft (1,370-3,660 m)

**SUCCESSIONAL STATUS :**
Slender wheatgrass is a pioneer in primary and secondary succession. It is among the first grasses to establish in gravelly pockets of soil on talus slopes of the Wasatch Plateau, Utah, and has colonized abandoned coal mine spoils in Alberta, Canada [17,46]. Slender wheatgrass is often dominant in early seral grassland communities due to its high seed production, and is also a dominant or codominant understory species in early seral forest and woodland communities [10,23]. Populations decrease in all three community types at later stages. Slender wheatgrass planted with crested wheatgrass (Agropyron cristatum) on a disturbed grassland range in Alberta declined from 69.5 percent of total herbage production in the first year to 2.6 percent after 4 years [23]. Litter buildup in older communities reduces flowering and seedling establishment in this species [41,43]. It is somewhat shade tolerant and persists in the community as a minor plant associate through the climax stage [23].

**SEASONAL DEVELOPMENT :**
Development varies depending upon latitude, elevation, and time of snowmelt. Generally, slender wheatgrass develops as follows [17,20,55]:

| | Northern Range | Southern Range |
|---|---|---|
| growth starts | following snowmelt | early spring |
| flowers | July-Aug | May-Oct |
| seeds ripe | Aug-Sept | June-Nov |
| seeds disseminated | Sept-Oct | Sept-Nov |

# FIRE ECOLOGY

## SPECIES: Elymus trachycaulus

**FIRE ECOLOGY OR ADAPTATIONS :**
Slender wheatgrass is a short-lived species that is favored by summer or fall fires [3,41]. The dense roots survive, and plants establishes from tillers and soil-stored seed in the seed bank.

**FIRE REGIMES :**
Find fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

**POSTFIRE REGENERATION STRATEGY :**
Caudex, growing points in soil
Initial-offsite colonizer (off-site, initial community)
Secondary colonizer - off-site seed

# FIRE EFFECTS

## SPECIES: Elymus trachycaulus

**IMMEDIATE FIRE EFFECT ON PLANT :**
Moderate-severity fire will top-kill slender wheatgrass and kill some tillers [59]. Fire effects upon this species differ according to the growth habit of the variety. Elymus trachycaulus spp. trachycaulus, for example, has moderately to densely clustered long leaves and stems. Studies show that bunchgrasses of this form generate high temperatures at the soil surface because fire burns down into the clump, resulting in tiller and root damage [64]. Tall, decadent plants with many dead basal leaves sustain the most fire damage. E. trachycaulus spp. latiglumis,

Currie and Smith [36] reported that smooth brome planted on low-fertility ponderosa pine (Pinus ponderosa) forest soils in Colorado declined under even light-intensity cattle grazing. They speculated that smooth brome is more likely to persist under cattle grazing on fertile soils.

Laycock and Conrad [77] used cattle to test several grazing systems on rangeland seeded to crested wheatgrasses (Agropyron cristatum and A. desertorum) and smooth brome in mountain big sagebrush (Artemisia tridentata spp. vaseyana) habitat in Utah. They found that average cattle weight gain was the same under all systems, but heavy June grazing in alternate years best promoted grass production.

Ungulates in Yellowstone National Park utilized smooth brome growing in association with other graminoids and forbs, but did not graze smooth brome where it grew in a monoculture [48].

Forestry: In British Columbia, height and biomass of lodgepole pine (Pinus contorta var. latifolia) seedlings established from a mix of lodgepole pine seed and smooth brome and other grass seed were less than height and biomass of lodgepole pine seedlings established from lodgepole pine seed sown alone [28].

Native grassland restoration: Smooth brome dominates many native grasslands and old fields [2]. Masters and Vogel [82] stated that on tallgrass prairie, it is usually found in areas with a history of overgrazing and/or fire exclusion. Grassland restoration efforts often include controlling smooth brome with cool-season grass herbicides such as atrazine and glyphosate, mowing, and/or prescribed fire [73].

Anderson [2] found that near Lincoln, Nebraska, fall application of glyphosate helped control smooth brome. Atrazine may not be as effective; other studies [83,96] have reported that while atrazine controlled other exotic cool-season grasses, it did not significantly reduce smooth brome.

Establishment and maintenance: Seed handling and planting guidelines for smooth brome are available [49,116,117]. Cultivars adapted to selected environments and/or regions are sold commercially [56,103,104,108,119,123].

Smooth brome requires fertile soil in order to maintain nutritional quality. On infertile soils it needs periodic fertilization or a companion nitrogen fixer. On rangelands smooth brome is usually planted in a mix with alfalfa (Medicago sativa), yellow sweet clover (Melilotus officinalis), or other legume species. Fertilization affects growth allocation: Watkins [120] found that fertilizers increased leaf and shoot growth but reduced rhizome and root growth.

Rhizomatous cultivars become sod-bound after several years unless litter is removed by grazing and/or fire [56,110].

## BOTANICAL AND ECOLOGICAL CHARACTERISTICS

### SPECIES: Bromus inermis

**GENERAL BOTANICAL CHARACTERISTICS :**
Smooth brome is an exotic, cool-season grass from 1.3 to 3.2 feet (0.4-1.0 m) tall. Blades are flat. The inflorescence is an open panicle from 2.4 to 6.8 inches (6-17 cm) long bearing 6 to 11-flowered spikelets. Lemmas have short awns (<2 mm) or are unawned [53,54,61].

Two principle types of smooth brome are recognized, the northern and southern. The northern type is weakly rhizomatous, with leaves well up on the stem and short glumes. A few northern cultivars are actually bunchgrasses. The southern type is strongly rhizomatous, with leaves near the base of the stem and long glumes. Other notable differences are earlier spring growth of the southern type and more even growth of the northern type through the growing season [55].

In a meadow in West Virginia on shallow silty loam, smooth brome roots grew to a depth of 18 inches (46 cm), with most of the root biomass occurring in the first 3 inches (7.6) of soil. (Average root

productivity was 717.7 lbs/acre inch at 0-3 inches below ground [52].) Witte [127] found roots as long as 9.4 feet (2.87 m).

Due to cloning, smooth brome is a long-lived species. Plantings have persisted for at least 60 years [98].

**RAUNKIAER LIFE FORM :**
Hemicryptophyte

**REGENERATION PROCESSES :**
Smooth brome reproduces by seed, rhizomes, and tillers. Spread by seed has been rated moderate, and vegetative spread has been rated good [97].

Smooth brome is usually cross-pollinated [72,86], although it may self-fertilize from different spikelets of the same plant [86]. McKone [72] found that seed set was significantly lower in smooth brome than in other brome species. Insect herbivory has been cited as a factor reducing seed set in smooth brome [86,91]. Seed yield of smooth brome broadcast-planted in Michigan 174 pounds per acre when grown with alfalfa and 121 pounds per acre when grown alone [122]. Seed has remained viable for 22 months to over 14 years [49,55]. Seed stored in a shed for 19 years showed 20 percent germination [66]. Seed requires stratification to germinate. Germinative capacity of fresh, stratified seed has varied from 83 to above 95 percent in the laboratory [49]. Optimal temperatures for germination in the greenhouse were from 68 to 86 degrees Fahrenheit (20-30 deg C) [49]. Like all cool-season species, however, smooth brome can germinate at lower temperatures. Bleak [17] reported that smooth brome seed sown in late fall to early winter in central Utah germinated and produced roots and shoots under deep snow cover. Light enhances germination but is not required [49].

Seedling growth is rapid [56,59]. Knobloch [72], who described germination and seedling development in detail, reported that 54 days after sowing, greenhouse-grown seedlings had 150-millimeter-long roots, five leaves, and had begun tillering. Baker and Jung [9] found that under greenhouse conditions, the optimal day temperature for growth was between 64.9 and 76.8 degrees Fahrenheit (18.3-24.9 deg C), and that food reserves were depleted less with low night temperatures than with warm night temperatures. Cultivars differ in rate of growth and drought tolerance [30].

**SITE CHARACTERISTICS :**
Smooth brome is widely adapted to a variety of sites. It is common in riparian zones, valley bottoms, and dryland sites. [48,56,119]. It is adapted to all soil textures [49,55,90], although it may not thrive on sand or heavy clay [119]. Smooth brome tolerates acid soils; it comprised the dominant cover on a coal spoil of pH 4.5 in British Columbia [56]. It does not grow on soils that are more than moderately alkaline [55]. It is fairly saline tolerant [56]. Smooth brome grows best on moist, well-drained soils [49], but tolerates poorly drained soils [32]. Smooth brome is best adapted to regions receiving more than 15 inches (380 mm) of annual precipitation [98,119]. Eleven inches (280 mm) of annual precipitation is the minimum that will support smooth brome without irrigation [98].

Some cultivars of smooth brome are adapted to northern latitudes and high elevations [60,102]. Smooth brome persists to about 9,000 feet (2,743 m) elevation in the northern Rocky Mountains [24,119] and to about 11,000 feet (3,300 m) in the central and southern Rocky Mountains [119]. General elevational ranges in several states are:

from 7,000 to 10,000 feet (2,134-3,048 m) in Arizona [69]
below 8,900 feet (2,700 m) in California [61]
from 4,500 to 10,000 feet (1,372-3,048 m) in Colorado [57]
from 4,096 to 10,352 feet (1,280-3,235 m) in Utah [121]

**SUCCESSIONAL STATUS :**
Smooth brome generally invades after disturbance and persists [19,20,37]. It is a common invader of disturbed prairie throughout the Great Plains [112,125,126]. In Yellowstone National Park, Wyoming, smooth brome cover was similar in young eastern cottonwood (Populus deltoides), mature eastern cottonwood, and grassland areas [19]. Boggs and Weaver [20] reported that along the Yellowstone River, moderate grazing increased the occurrence of shrubs in mature eastern cottonwood, and severe grazing converted the area to smooth brome, timothy (Phleum

pratense), and Kentucky bluegrass (Poa pratensis).

Smooth brome tolerates moderate shade to full sun [49,56]

**SEASONAL DEVELOPMENT :**
Smooth brome undergoes fall green-up. Inflorescences are initiated during cool, short fall days [90]. In colder climates, smooth brome is dormant in winter. It may remain green year-round in southern climates [76]. Spring growth begins early in the season [110,107]. Lengthening culms expose the panicles in late spring to early summer [90], and smooth brome flowers in summer. In Minnesota, flowering occurred from early to late June [80,86]. It occurred in late May or early June in Ames, Iowa, with later, sporadic flowering [72]. Phenology is delayed in northern latitudes and high elevations. Smooth brome on the Wasatch Plateau of Utah flowers 85 to 102 days after snowmelt [44]. Seed matures in early to late summer [49]. Smooth brome grows throughout the growing season when soil water is adequate. Under dry soil conditions it becomes dormant, but it resumes growth when soils moisten [16].

# FIRE ECOLOGY

## SPECIES: Bromus inermis

**FIRE ECOLOGY OR ADAPTATIONS :**
Most smooth brome cultivars are rhizomatous [56,110], and survive fire by sprouting from rhizomes. Weakly rhizomatous or bunchgrass types probably regenerate after fire primarily by tillering. Rates of postfire recovery probably differ between cultivars, with rhizomatous types recovering more quickly than bunchgrass types, but such differences have not been documented in the literature.

Periodic early spring or fall fire promotes rhizomatous smooth brome by removing litter from sod-bound plants [56,110].

**FIRE REGIMES :**
Find fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

**POSTFIRE REGENERATION STRATEGY :**
Rhizomatous herb, rhizome in soil
Tussock graminoid

# FIRE EFFECTS

## SPECIES: Bromus inermis

**IMMEDIATE FIRE EFFECT ON PLANT :**
Smooth brome is probably top-killed by fire.

**PLANT RESPONSE TO FIRE :**
Early spring (late March-April) or late-season (late summer-fall) fire can increase smooth brome productivity [62,65], especially when smooth brome has become sod-bound. Late spring fire generally damages cool-season grasses such as smooth brome [8,82]. Old [93], Kirsch and Kruse [71], and Blankespoor [15] have reported reductions in smooth brome with late spring burning.

Old [93] attributed decreases in smooth brome after late April fire to the advanced stage of development of smooth brome. Rate of smooth brome regrowth after fire cannot always be predicted based solely upon season of burning and attendant phenological stage, however. Blankenspoor and Larson [16] cited soil moisture and nutrient levels and soil texture as factors other than phenological stage that may affect smooth brome rate of recovery.

In order to determine at which stage of growth smooth brome is most susceptible to fire, Willson [124] prescribe-burned smooth brome at tiller emergence (late March at the Mead, Nebraska, study site), tiller

SPECIES: Pascopyrum smithii



GENERAL BOTANICAL CHARACTERISTICS:
Western wheatgrass is a long-lived, native perennial, cool-season, endomycorrhizal grass [114,115]. It is an aggressive sod-forming grass characterized by an abundance of long, branched rhizomes [10,27]. Rhizomes allow plants to survive moderately severe drought [152]. The erect culms reach 12 to 36 inches (30-90 cm) in height [130].

Rhizomes lie 0.5 to 2 inches (1.3-5 cm) below the soil surface. The highly branched root system may penetrate the soil to a depth of 7 feet (21 m). In the deep rich soils of eastern Nebraska and Kansas, roots may extend as deep as 11.8 feet (3.6 m). Root extensions in more arid eastern Colorado may extend downward to depths of only 4.9 feet (1.5 m) [34]. In dry grasslands of Montana, only 6% of the roots of western wheatgrass were observed in the top 0 to 0.5 inch (0-1 cm) soil layer.

Longevity of western wheatgrass roots was studied by banding roots of plants grown in containers from seed. In the second year 55 and 60% of the banded roots were dead. By the end of the second summer western wheatgrass roots had a survival of 42% [154]. Zhang and Romo [174] report tiller longevity of 2 to 3 years in Saskatchewan.

RAUNKIAER LIFE FORM:
Geophyte

REGENERATION PROCESSES:
Western wheatgrass regenerates vegetatively through rhizomes to form uniform stands [68]. It also spreads via seeds. A limited seed supply usually matures late, but this is offset by reproduction from rootstocks [150]. Stands are slow to develop from seed [27], but once established are vigorous, hardy, and drought resistant. Seeds germinate slowly, but a fairly uniform sod is usually obtained within 2-3 years [10].

Western wheatgrass exhibits a low and much-delayed germination at 66 to 73 degrees Fahrenheit (19-2 $^{o}$C) [26,114,145]. Germination is most successful with alternating temperatures of 59 degrees Fahrenheit (15 $^{o}$C) and 86 degrees Fahrenheit (30 $^{o}$C) [39]. Light does not affect germination [122,141].

Peak germination response for western wheatgrass was 94% at 65 degrees Fahrenheit (18.5 $^{o}$C) for 8 hours and 50 degrees Fahrenheit (10 $^{o}$C) for 16 hours. The mean germination time was 11.8 days. In constant temperature without light, germination percentages decrease [93,122].

SITE CHARACTERISTICS:
Western wheatgrass is drought tolerant, and established stands can survive even extended periods of drought [27,68,130]. It commonly occurs along ephemeral creeks where it grows through thick layers of silt in areas that flood in spring [9,68]. It also grows on well-drained upland sites [130]. Western wheatgrass grows in mesic areas, swales, overflow sites, and subirrigated lowlands. Western wheatgrass is tolerant of periodic flooding, poor drainage, and water tables within 6 inches (15 cm) of the soil surface [27].

Western wheatgrass commonly grows on medium to heavy textured soils [27]. It can grow on even heavy gumbo soils, but does poorly on sand [9,130]. In parts of Colorado, western wheatgrass grows on clayey soils with an

average pH of 7.78 [9].Western wheatgrass is highly tolerant of saline to alkali soils [27]. Western wheatgrass is adapted to areas that receive 14 to 35 inches (360-870 mm) of average annual precipitation [130].

Elevational ranges vary as follows [45]:

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3,600 to 10,000 feet (1098-3049 m) in Colorado
2,400 to  3,600 feet (732-1098 m)  in Montana
4,200 to  7,500 feet (1280-2677 m) in Utah
3,400 to  8,200 feet (1037-2500 m) in Wyoming
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SUCCESSIONAL STATUS:
Western wheatgrass occurs in all seres. It is however, frequently described as a "late successional species" [89,127]. It is present in many climax plant communities [115]. Western wheatgrass increases during secondary succession. Its ability to rapidly reestablish after disturbance is attributed to its rhizomatous growth habit [123]. Samuel and Hart [124] report that it typically appears much earlier and in much greater abundance than other long-lived perennial grasses on disturbed sites in Wyoming.

Western wheatgrass grows in a variety of successional stages in sagebrush (*Artemisia* spp.) communities. It has been described as a "mid-seral species" in semi-arid sagebrush communities of northwestern Colorado. In these sagebrush communities, annual forbs dominate disturbed sites for the first 2 years after disturbance. By year 3, cheatgrass *(Bromus tectorum)* typically becomes dominant and perennial grasses such as western wheatgrass become dominant by the 4th year after disturbance [104]. In big sagebrush communities, western wheatgrass may among the earliest species to become prominent following disturbance [19]. In Wyoming big sagebrush communities, western wheatgrass dominates "late intermediate seral stages" in steppe communities [16]. It replaces blue grama in "early intermediate seral stages" and is replaced by big sagebrush later in succession.

Western wheatgrass is common on disturbed sites (abandoned towns) in parts of southwestern Montana [92]. During the drought of the 1930s, western wheatgrass supplanted tall grasses over much of the eastern Kansas prairie [113]. Grasses reverted to the original composition as more "normal" (more moist) conditions returned.

In certain Montana riparian communities, years of heavy grazing can cause cottonwood stands to be replaced by shrub/grass communities dominated by silver sagebrush *(Artemisia cana)*, greasewood *(Sarcobatus vermiculatus)*, and western wheatgrass [70].

SEASONAL DEVELOPMENT:
Western wheatgrass produces best growth in spring. Flowering occurs in June, and seeds ripen in August or September [150]. In South Dakota, vegetative growth typically begins in early June, flowering begins by mid to late June, and seeds shatter by mid-August [85]. Flowering dates by state are as follows [45]:

| State | Earliest date observed | Latest date observed |
|---|---|---|
| CO | June | August |
| MT | June | August |
| ND | June | July |
| WY | June | August |

A representative phenology for a population of western wheatgrass from the northern Great Plains is as follows [143]:

| | |
|---|---|
| Dormancy | 5-20 November |
| Early growth | 15-20 April |
| Rapid growth | 1-10 June |
| Boot stage | 1-15 August |

A western Wyoming study of phenological development of western wheatgrass from 1973 to 1975 showed that "normal" seed dissemination was difficult to predict as inflorescences appearing in July did not necessarily produce viable seed. Seed may not shatter until late fall or early the following summer [90].

| Phenology | Range | Average |
|---|---|---|
| Growth initiation | March 5-April 26 | March 15 |
| Full bloom | June 20-July 20 | July 10 |
| Start of seed dissemination | July 25-November 20 | August 15 |

In northeastern Colorado, the following phenological development was observed [44]:

| | |
|---|---|
| Floral buds and open flowers | Early June |
| Floral buds, open flowers and ripening fruit | Mid-June |
| Buds, flowers, green and ripe fruit | Early June |
| Bud, flowers, green, ripe fruit and dispersing seed | End of July-Early August |
| Green and ripe fruit, dispersing seed and senescence | Early October |

In a 2nd Colorado study, seasonal growth was initiated by the 2nd or 3rd week of April and flowering began by the 1st week of June, with maximum flowering by the 3rd week of June. Maximum rate of leaf area increase occurred from late May through June [109]. In Texas, western wheatgrass generally begins fall growth by September. The short growing period in the fall is followed by peak growth in late spring (April) when maximum leaf widths are reached. Plants did not grow during winter, even under irrigation [129].

The growth and phenological stages of western wheatgrass plants are inversely related to carbohydrate reserve storage. Lowest root and crown total nonstructural carbohydrate (TNC) levels are reached during the 3rd leaf stage in April. The highest TNC levels occur during the 5th leaf stage in late June and at the end of the growing season, fall quiescence [106]. Seed maturity occurs when water concentrations reach approximately 300 to 350 g/kg (dry weight basis) [17]

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# FIRE ECOLOGY

SPECIES: Pascopyrum smithii

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FIRE ECOLOGY OR ADAPTATIONS:
The major adaptation of western wheatgrass to fire is its rhizomatous growth form [151]. Western wheatgrass is characterized by loosely clustered, coarse culms with a minimum of leafy material. During a fire these culms usually burn rapidly with little heat transferred downward into meristematic tissue.

Fire did not alter species composition after fire in a South Dakota mixed-grass prairie community containing western wheatgrass [158]. This may not be true of all communities in which western wheatgrass occurs. To learn more about the fire regimes in specific communities in which western wheatgrass occurs, refer to the FEIS summary for those species, under "Fire Ecology or Adaptations."

POSTFIRE REGENERATION STRATEGY:
Rhizomatous herb, rhizome in soil

FIRE REGIMES:
Find fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

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