

# *Alnus maritima* ssp. *oklahomensis* Performance in Non-Irrigated Landscapes in the Intermountain West<sup>1</sup>

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## Abstract

*Alnus maritima* (Marsh.) Muhl. ex Nutt. ssp. *oklahomensis* Schrader & Graves has potential for ornamental use in the Intermountain West. Because this taxon is native to low-elevation wetlands, we sought to determine its response to the dry soils and climate of northern Utah. Although seeds sown directly at three non-irrigated sites in northern Utah either did not germinate or germinated and died, seeds planted in a greenhouse in soils from the three sites did germinate and survive. Hardened plants grown from these seeds and installed at the same three sites overwintered, broke bud and leafed out, but none survived longer than four weeks after bud break without irrigation. Ratings of progression of bud break were greatest (3.5 to 3.8 out of 5), and leaf scorch least (16.0 to 16.7%), in areas with either low light or wet soils. Plants from the same crop left in their containers on an irrigated gravel pad under partial shade showed no signs of stress. Our results suggest that *A. maritima* ssp. *oklahomensis* cannot survive under non-irrigated outdoor conditions in Intermountain West landscapes and may require irrigation and protection from sun and wind for optimal performance.

**Index words:** germination, light intensity, soil moisture, seaside alder, arid landscapes.

## Significance to the Nursery Industry

*Alnus maritima* (Marsh.) Muhl. ex Nutt. is a rare shrub species that is limited in its natural occurrence to three small but widely separated areas in North America: in Delaware and Maryland along the Delmarva Peninsula (ssp. *maritima*); in and around one swamp in Georgia (ssp. *georgiensis*); and in two counties in Oklahoma (ssp. *oklahomensis*) (10). All states to which *A. maritima* is native consider the species rare, threatened, or imperiled. Understanding the factors that limit the growth and landscape establishment of this species will aid in its adoption by the nursery industry. Recently a cultivar, 'September Sun', was selected from a trial of *A. maritima* ssp. *oklahomensis* seedlings on the campus of Iowa State University for release to the nursery industry (4). The cultivar is a large shrub or small multi-trunked tree with a rounded, vase-shaped canopy, dark green glossy leaves, and the unusual habit of producing golden pendulous catkins in late summer. The current study, although not directly involving the cultivar, was a test of the potential for introduction of the taxon to managed landscapes in the northern regions of the Intermountain West. Results suggest that plants of *A. maritima* ssp. *oklahomensis* will not grow in non-irrigated landscapes in the Intermountain West and may require irrigation and at least partial shade for successful transplant survival and establishment. Plants in colder areas may need protection from wind during years when winter snow cover is sparse. Future work should investigate irrigation and degree of shade requirements for optimal landscape performance.

## Introduction

*Alnus maritima* (Marsh.) Muhl. ex Nutt. ssp. *oklahomensis* Schrader & Graves (10, 12) is a rare alder species with

attributes that make it desirable as a potential ornamental landscape plant. It is a fast-growing large shrub or multi-trunked tree with a broadly rounded canopy, dense foliage, and 8 cm (3 in) long pendulous catkins that appear in mid-August to late September, before the leaves turn color in the fall. Limited in its natural occurrence to water-saturated soils in only two counties in south-central Oklahoma (8), this taxon is one of three widely disjunct subspecies of *A. maritima*, all native to the United States. Given its hardiness to USDA zone 3a (11), tolerance to a wide range of soil moisture conditions from dry to water-saturated soils (13), and relative shade intolerance (3, 14), *A. maritima* seems a likely candidate for introduction to ornamental landscapes in the Intermountain West region.

The geographic region in north and north-central Utah located along the Wasatch Range is the most urbanized area in the state (1). It is characterized by environmental conditions similar in some ways to those in Ames, IA, where published field tests of *A. maritima* were performed. Urban areas along the Wasatch Range are designated to be in USDA hardiness zones 4–5, but more realistically they range from zones 3–6, according to data gathered from local weather stations (2). This modification of the USDA hardiness ratings is critical in the Intermountain West, where rapid changes in elevation can create microclimates that may influence the success or failure of a planted species. Areas along the Wasatch Range experience seasonal variation in soil moisture, with soils wetter in spring (mostly from snowmelt) and drier in summer and fall (when little to no precipitation occurs). Many homeowners in this region use flood irrigation from purchased rights to water flowing down from the mountains by way of canals for watering their landscapes, so the capacity for landscape plants installed in these areas to tolerate some degree of flooding is useful. The sun is a constant factor in Utah, and unless protected by shade from neighboring plants or built structures, plants are exposed to full-sun conditions during much of the growing season.

The objectives of this study were to test seeds for their germinability, and to evaluate performance of young container transplants to non-irrigated conditions in three diverse habitats representative of species composition and environmental conditions that could be expected in and around residential

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areas in north-central Utah. The Utah Botanical Center in Kaysville (Davis County) was chosen as the test site because of the diversity of landscape conditions within the Center, and because transplants could be monitored easily by staff.

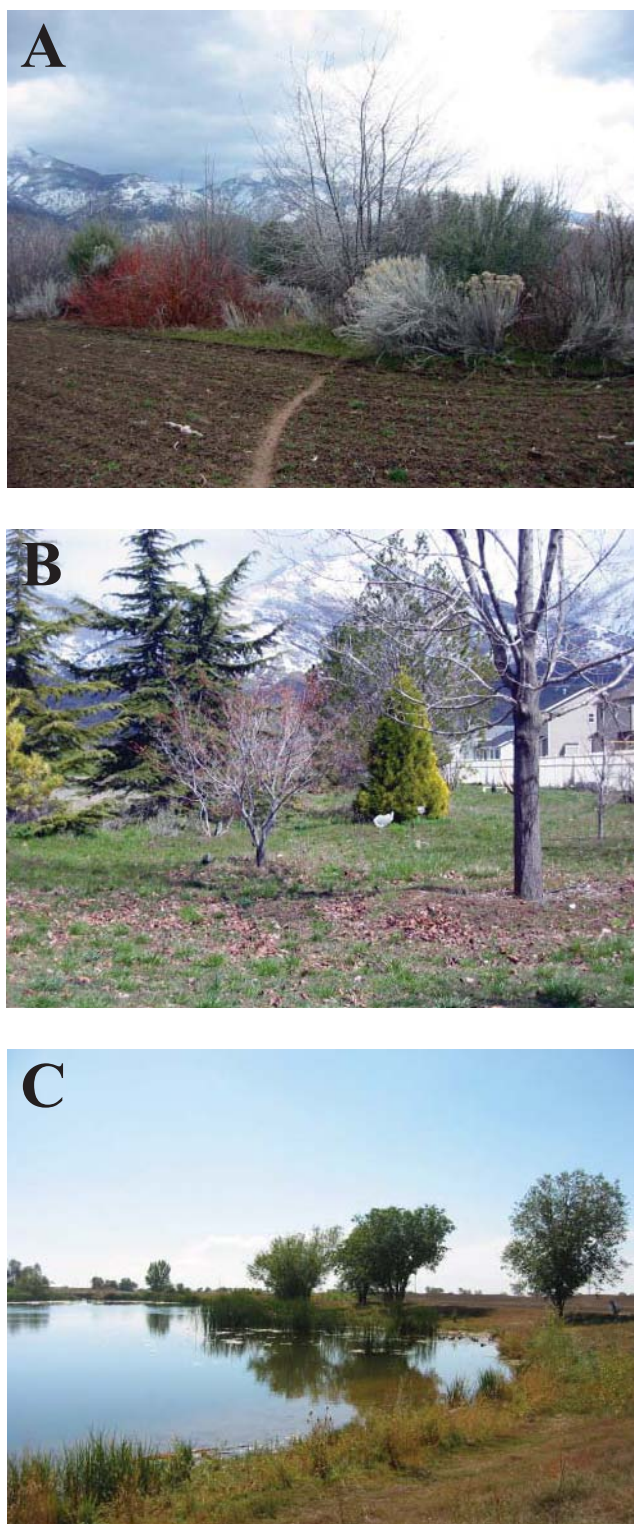
## Materials and Methods

**Seed germination and seedling survival.** In October 2004, donated wild-collected seeds of *A. maritima* ssp. *oklahomensis* from the population indigenous to Oklahoma (8) were sown directly at three non-irrigated sites at the Utah Botanical Center in Kaysville, UT. Each of the three sites contained 18 propagation points, 1 m (3.3 ft) apart. Each propagation point consisted of a hole, into which five seeds each were sowed to a depth of 5 mm (0.2 in), watered in thoroughly, and covered with raised chicken wire to prevent access to birds and small mammals.

The first site (hereafter referred to as the 'native site'), 41°1.0'13.0"N, 111°55'49.6"W, elevation 1335 m (4379 ft), is an 18-year-old plot containing a former blocked and replicated study of six shrub species native to Utah, including ocean spray (*Holodiscus discolor*), silver sagebrush (*Artemisia cana*), redosier dogwood (*Cornus sericea*), rubber rabbitbrush (*Chrysothamnus nauseosus*), curl-leaf mountain mahogany (*Cercocarpus ledifolius*), chokecherry (*Prunus virginiana*) (Fig. 1A). Seeds of *A. maritima* ssp. *oklahomensis* were sowed in two rows within a 1.5 m (4.9 ft) wide clearing in the center of the plot. The second site (hereafter referred to as the 'tree/turf site'), 41°1.0'12.8"N, 111°56.0'13.9"W, elevation 1324 m (4345 ft), is a site in which mature ornamental tree species are growing in turfgrass (Fig. 1B). Seeds at this site were planted in a grid alongside, but not closer than 3 m (10 ft) to, European beech (*Fagus sylvatica*) on the west, not closer than 15 m (49.2 ft) to an aluminum fence on the south, and bordered by open space on the east and north. The third site (hereafter referred to as the 'pond site'), 41°1.0'32.6"N, 111°56.0'27.7"W, elevation 1318 m (4323 ft), is the site of a manufactured wetland (Fig. 1C). Seeds were planted on the northwest edge of the pond in two adjacent plots, each with nine propagation points and separated by existing plant materials. Each plot consisted of three rows; the first row was 1 m (3.3 ft) from the pond, and consecutive rows were 1 m (3.3 ft) from each other up the embankment. Seeds were not planted closer than 1 m (3.3 ft) to the pond to allow for periodic manual raising and lowering of pond levels by botanical center staff. Associated species included narrowleaf willow (*Salix exigua*), Booth's willow (*Salix boothii*), river hawthorn (*Crataegus rivularis*), common threesquare (*Schoenoplectus pungens* var. *longispicatus*), and common spikerush (*Eleocharis palustris*).

At the time of sowing, 500 ml (1 pt) of soil from various locations at each site was collected and sent to the Utah State University Analytical Laboratories for analysis. Native-site soil was a loam and contained 3.22 mg·kg<sup>-1</sup> nitrate-N and 1.6% organic matter. Tree/turf-site soil was a loam and contained 4.72 mg·kg<sup>-1</sup> nitrate-N and 2.9% organic matter. Pond-site soil was a silt loam containing 5.36 mg·kg<sup>-1</sup> nitrate-N and 1.4% organic matter. Previous analyses determined that the pH of soils at the Utah Botanical Center ranges from 7.3 to 7.6. Soil also was collected from each site for use in a greenhouse germination study.

On May 10, 2005, donated seeds from natural populations of *A. maritima* ssp. *oklahomensis* were rinsed in distilled water and stratified between moist filter papers in



**Fig. 1.** Photographs of experimental sites at the Utah Botanical Center in Davis County, UT, taken in fall 2004. The native site is in the midst of tilled but fallow land, and it contains mature Utah native shrubs (A). The tree/turf site is adjacent to a residential area on the south and to recently tilled but unused land on the north. It is planted with mature ornamental non-Utah-native trees in Kentucky bluegrass (B). The pond site is a manufactured wetland to the west of the main Botanical Center grounds. Plants typical of northern Utah wetlands were installed prior to direct-seeding of *Alnus maritima* ssp. *oklahomensis*, and these plants provided shade to *A. maritima* ssp. *oklahomensis* installed closest to the pond (C).

petri dishes at 4C (39.2F) for 8 weeks. Stratified seeds (60 per flat) were sowed into 20.3 × 40.6 × 5 cm (8 × 16 × 2 in) seed flats, each flat containing soil from one of each of the three sites or a commercial germination mix (Sunshine™ Germination Mix No. 3, Sun Gro Horticulture, Bellevue, WA). Each flat was an experimental unit, and there were three repetitions per substrate ( $N = 3$ ). Flats were held on a greenhouse bench where natural daylight was extended to provide 16-hr photoperiods by using 400W, high-pressure sodium lamps. Daytime air temperature in the greenhouse averaged 24C (75F), mean relative humidity was 52%, and mean daytime photosynthetically active radiation (PAR) was 969  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . Flats were irrigated by hand twice daily to field capacity with a misting wand. Sixty stratified seeds also were placed between moist filter papers in a petri dish and allowed to germinate at room temperature on a laboratory bench. Cumulative number of seeds germinated in each flat was recorded daily from May 18 to May 31. At the end of the experiment, ungerminated seeds were recovered from substrate by rinsing through a strainer, and they were tested for viability by using tetrazolium (6) to assure homogeneity of viable, non-dormant seed distribution across substrates.

Germinated seedlings were transplanted from flats into 15.2 cm (6 in) diameter round plastic pots and grown through spring and summer in the greenhouse. They were transferred to a cold-frame outside of the greenhouse to overwinter in fall 2005. In spring 2006, plants were transferred to #1-size containers and allowed to harden on an irrigated holding pad under increasing periods of sunlight at the Utah State University Greenville research farm in Logan, UT.

**Plant survival in the landscape.** In October 2006, 17-month-old hardened plants of *A. maritima* ssp. *oklahomensis* were assigned randomly and installed at the Utah Botanical Center in the same three sites, and in a similar arrangement, as seeds were sown (15 plants at each site). Plants were ir-

rigated deeply after transplanting, and plant height, width, and numbers of stems per plant were recorded. Transplants were monitored for damage or disappearance every two weeks during the dormant season.

On April 4, 2007, progression of bud break and percentage leaf scorch were recorded at each site. Leaf scorch was measured as an indicator of damage and dieback due to heat and water stress. Spring bud progression was measured using a 5-point rating system: 1 = no bud break, 2 = moderate bud break, 3 = substantial bud break, 4 = < 50% of leaves fully expanded, 5 =  $\geq$  50% of leaves fully expanded. Leaf scorch was recorded as a percentage of total leaf area on a plant. Light was measured as photosynthetically active radiation, and measurements were taken between 1000 and 1200 h, 0.6 m (2 ft) from the ground above each plant, by using a light meter fitted with a 50 cm (20 in) integrated line sensor (LQM50-10, Apogee Instruments, Logan, UT). Mean PAR intensities were 440, 822, and 1,025  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  at the native, tree/turf, and pond sites, respectively (Table 1). Soil moisture was measured at a depth of 20 cm (8 in) within each transplant root zone by using a HydroSense® CS620 Time-Domain Reflectometer fitted with 20 cm (8 in) probe rods (Campbell Scientific, Logan, UT). For analysis of progression of bud break and leaf scorch, transplants were grouped into high-light ( $\geq$  50%), moderate-light (25–49%), and low-light (< 25%) subcategories based on percentage of full sun, which was measured at 1,780  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  PAR at 1100 h on the day of data collection; they also were grouped into wet-soil (> 50% volumetric water content) and dry-soil (< 10% volumetric water content) subcategories.

**Statistical analysis.** Data were analyzed for main effects of growing substrate on seed germination, and of light and soil moisture on spring bud progression and leaf scorch; interaction (light × soil moisture) effects on spring bud progression and leaf scorch; and means separation statistics using the general linear models procedure of SAS/STAT® software version 9.1 (7). Data were tested for homogeneity of variance using Levene's test (7). Data within light and soil moisture levels were analyzed separately due to a lack of interaction between the two variables. Correlations between variables were analyzed using Pearson's correlation of the CORR procedure of SAS/STAT software.

## Results and Discussion

**Seed germination and seedling survival.** Seeds of *Alnus maritima* ssp. *oklahomensis* sown directly at each of the three sites either failed to germinate, or seedlings died shortly after germination. Source of collected soil did not influence the percentage germination or seedling survival from seeds sown in flats in the greenhouse, where overall mean germination was 83% and net seedling survival averaged 20% (Table 2). Only seeds sown in soil from the native site exhibited germination rates lower than seeds sown in a soilless substrate. Survival of seedlings from seed sown in soils from all three sites was 74% lower than that of seedlings from seed sown in a soilless substrate ( $P < 0.05$ ). Tetrazolium testing of seeds germinated in a petri dish showed that 93.3% of seeds used in this experiment were viable (Table 2). Tetrazolium tests of recovered ungerminated seeds across all four substrates indicated no differences in percentage of seeds that were dormant ( $P = 0.6315$ ), hard ( $P = 0.1109$ ), or dead ( $P = 0.4202$ ).

**Table 1. Observations of plants of *Alnus maritima* ssp. *oklahomensis* and environmental conditions at the Utah Botanical Center (UBC) in Kaysville, UT.**

|                                                                  | Native site | Tree/turf site | Pond site  |
|------------------------------------------------------------------|-------------|----------------|------------|
| Condition of plants: <sup>z</sup>                                |             |                |            |
| Bud break (no. of plants)                                        | 13          | 8              | 11         |
| Leafing out/no apparent damage (no. of plants)                   | 4           | 0              | 5          |
| Leafed out fully (no. of plants)                                 | 4           | 2              | 6          |
| Leaf scorch (%) <sup>y</sup>                                     | 20.3b       | 53.0a          | 45.7a      |
| Plants alive 4 weeks after bud break                             | 5           | 0              | 0          |
| Mean PAR ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ) | 440         | 822            | 1,095      |
| Mean soil moisture (%)                                           | 4           | 4              | 40         |
| Conditions at the UBC weather station: <sup>x</sup>              |             |                |            |
| Maximum daily air temperature (C/F)                              |             |                | 8.4/47.1   |
| Lowest recorded temperature (C/F)                                |             |                | -18.7/-1.7 |
| Relative humidity (%)                                            |             |                | 41.0       |
| Precipitation (cm-wk <sup>-1</sup> /in-wk <sup>-1</sup> )        |             |                | 0.61/0.24  |
| ET <sub>o</sub> (cm-wk <sup>-1</sup> /in-wk <sup>-1</sup> )      |             |                | 1.17/0.46  |
| Precipitation ÷ ET <sub>o</sub>                                  |             |                | 0.52       |

<sup>x</sup>On April 4, 2007 ( $N = 15$ ).

<sup>y</sup>Means with the same letter are not significantly different at  $P < 0.05$  according to Fisher's least significant difference test.

<sup>z</sup>Conditions represent means from November 1, 2006, to April 26, 2007.

**Table 2. Influence of growing substrate on seed germination and survival of *Alnus maritima* ssp. *oklahomensis* maintained in a greenhouse in northern Utah. Seeds were cold-stratified prior to sowing and allowed to germinate from May 10 to May 31, 2005.**

| Growing substrate       | Germination <sup>z</sup><br>(%) | Tetrazolium test       |             |             | Net seedling survival <sup>y</sup><br>(%) |
|-------------------------|---------------------------------|------------------------|-------------|-------------|-------------------------------------------|
|                         |                                 | Fresh (dormant)<br>(%) | Hard<br>(%) | Dead<br>(%) |                                           |
| Soiless germination mix | 96.2a                           | 10.6a                  | 1.7a        | 3.3a        | 78.3a                                     |
| Pond-site soil          | 87.3ab                          | 7.8a                   | 2.8a        | 12.2a       | 23.7b                                     |
| Tree/turf-site soil     | 85.4ab                          | 11.1a                  | 8.3a        | 12.2a       | 23.4b                                     |
| Native-site soil        | 77.1b                           | 16.1a                  | 8.3a        | 15.0a       | 11.9b                                     |
| Petri dish              | 93.1                            | 3.3                    | 0           | 6.7         | —                                         |

Note: Means within each column followed by the same letter are not significantly different at  $P < 0.05$  according to Fisher's least significant difference test.

<sup>z</sup>Germination is calculated as percent of non-dormant seeds.

<sup>y</sup>Germinated seedlings that survived the 21-day germination period.

That *A. maritima* ssp. *oklahomensis* did not grow from seeds sown directly at these sites in the fall is consistent with an earlier study conducted at Iowa State University (9) that demonstrated decreased germination after exposure of seeds to temperatures of  $-18$  to  $-15^{\circ}\text{C}$  ( $-0.4$  to  $5^{\circ}\text{F}$ ), which are typical of its native habitat. These temperatures are similar to the lowest recorded temperature in the winter of 2006–2007 at the Utah Botanical Center of  $-18.7^{\circ}\text{C}$  ( $-1.7^{\circ}\text{F}$ ) (Table 1). In its native habitat, few plants of this fall-blooming taxon reproduce from seed (15), and most colonies of *A. maritima* in its disjunct locations are thought to be primarily clonal (9).

**Plant performance in the landscape.** All containerized plants of *A. maritima* ssp. *oklahomensis* transplanted at the three non-irrigated sites ultimately died, but some survived longer than others. On April 4, 2007, the numbers of transplants that had broken dormancy and leafed out without damage were similar at the native and pond sites (Table 1). Only half the plants installed at the tree/turf site broke dormancy, and of those, none had leaves without damage. Overall survival time was longest at the native site, and transplants at this site lived at least four weeks longer than those installed at the other two sites. At the time of transplanting in October 2006, plant height averaged 38.0, 43.7, and 37.6 cm (15, 17.2, and 14.8 in) at the native, tree/turf, and pond sites, respectively. Mean plant width was 13.6, 15.6, and 17.0 cm (5.4, 6.1, and 6.7 in), respectively. Number of stems per plant averaged 12.9, 12.3, and 8.2, respectively.

Light exposure and soil moisture differed between and within sites, and these parameters were related to the varying rates of progression of bud break and leaf scorch across and within sites (Table 3). Across all sites, ratings of progression of bud break were greatest for transplants under high moisture and/or low to moderate light. Progression of bud break was greatest at the pond site under moderate light and high soil moisture conditions, but similar ratings were noted at the native site under low to moderate light and dry soil conditions. Bud-progression ratings were low for transplants at the tree/turf site, even under only moderate light conditions. These transplants at the tree/turf site also were noted to have few buds, located at the base of the stems only (data not shown). Transplants at the tree/turf site were more exposed to wind than were transplants at the other two sites, because the surrounding plant materials were mature beech trees. These mature trees provided partial shade for some of

the transplants in the spring, but gave little protection at the level of the alder canopy from cold, drying winter winds, which may have desiccated growing points on the upper parts of the alder stems. In contrast, transplants at the native site were protected by an overgrowth of native shrub species (Fig. 1A), some of which are semi- or fully evergreen and could have provided protection from the wind even in the dormant season.

Across all sites, leaf scorch was greatest on transplants exposed to the highest light intensities (Table 3). A similar

**Table 3. Influence of light and moisture levels on progression of bud break and leaf scorch of *Alnus maritima* ssp. *oklahomensis* at three sites at the Utah Botanical Center in Kaysville, UT**

|                                        | Site                    |                         |                         | Across sites |
|----------------------------------------|-------------------------|-------------------------|-------------------------|--------------|
|                                        | Native                  | Tree/turf               | Pond                    |              |
| Progression of bud break: <sup>z</sup> |                         |                         |                         |              |
| High light <sup>y</sup>                | — <sub>n = 1</sub>      | 2.0c <sub>n = 8</sub>   | 2.3c <sub>n = 10</sub>  | 2.2b         |
| Moderate light                         | 2.8abc <sub>n = 8</sub> | 2.4bc <sub>n = 7</sub>  | 3.8a <sub>n = 5</sub>   | 2.9ab        |
| Low light                              | 3.5ab <sub>n = 6</sub>  | —                       | —                       | 3.5a         |
| Wet soil <sup>x</sup>                  |                         |                         |                         |              |
| Dry soil                               | —                       | —                       | 3.8a <sub>n = 5</sub>   | 3.8a         |
|                                        | 3.1ab <sub>n = 15</sub> | 2.2b <sub>n = 15</sub>  | 2.3b <sub>n = 10</sub>  | 2.6b         |
| Leaf scorch (%):                       |                         |                         |                         |              |
| High light                             | — <sub>n = 1</sub>      | 53.8ab <sub>n = 8</sub> | 60.5a <sub>n = 10</sub> | 54.5a        |
| Moderate light                         | 25.6bc <sub>n = 8</sub> | 52.1ab <sub>n = 7</sub> | 16.0c <sub>n = 5</sub>  | 34.2b        |
| Low light                              | 16.7c <sub>n = 6</sub>  | —                       | —                       | 16.7b        |
| Wet soil                               |                         |                         |                         |              |
| Dry soil                               | —                       | —                       | 16.0b <sub>n = 5</sub>  | 16.0a        |
|                                        | 20.3b <sub>n = 15</sub> | 53.0a <sub>n = 15</sub> | 60.5a <sub>n = 10</sub> | 42.6a        |

Note: Means within a light or moisture condition followed by the same letter are not significantly different at  $P < 0.05$  according to Fisher's least significant difference test. A dash indicates the condition was not present at that site, or there was no replication for analysis. Across-site data were analyzed separately within light or moisture categories.

<sup>z</sup>Progression of bud break was measured using a 5-point rating system: 1 = no bud break, 2 = moderate bud break, 3 = substantial bud break, 4 =  $< 50\%$  of leaves fully expanded, 5 =  $\geq 50\%$  leaves fully expanded.

<sup>y</sup>Results for high, moderate, and low light were from plants growing under  $\geq 50\%$  ( $N = 19$ ), 25 to 49% ( $N = 20$ ), and  $< 25\%$  ( $N = 6$ ) full sun, respectively. Full sun was measured at  $1,780 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  PAR at 1100 h on the day of data collection.

<sup>x</sup>Results for wet and dry soils were from plants growing in soils with  $> 50\%$  ( $N = 5$ ) and  $< 10\%$  ( $N = 40$ ) volumetric water content, respectively.

trend was noted for transplants in drier soil; however, the difference in leaf scorch between transplants in wet and dry soils was not significant statistically, probably because of the limited numbers of transplants exposed to wet soil (5 out of 45 total plants). Leaf scorch was greatest among transplants under high light and low soil moisture at the pond site; effects of light and moisture are difficult to separate, however, because the area of low soil moisture was also under high light at that site (data not shown). Leaf scorch was similarly high at the tree/turf site, even at only moderate light levels. Leaf scorch at the native site was only 38 to 44% of that at the other two sites overall (Table 1), and less than 40% of that at the other two sites for transplants in dry soil (Table 3). Mean light intensities were 40 and 50% lower at the native site than at either the pond or the tree/turf site, respectively (Table 1).

Leaf scorch was positively correlated with light overall (Fig. 2A), and weakly negatively correlated with soil moisture level at the pond site only (Pearson's correlation coefficient  $-0.5028$ ;  $P = 0.0561$ ) (data not shown). Progression of bud break was negatively correlated with light overall (Fig. 2B) and positively correlated with soil moisture level at the pond site only (Pearson's correlation coefficient  $0.5511$ ;  $P = 0.0332$ ) (data not shown). There was no interaction between light and soil moisture on either leaf scorch ( $P = 0.4025$ ) or progression of bud break ( $P = 0.4915$ ).

Although natural populations of *A. maritima* are likely maintained by vegetative reproduction rather than repro-

duction by seed, work by Schrader and others (14) suggests that its relative shade intolerance has limited the natural distribution of *A. maritima* to only three small, disjunct locations in the United States, in areas with water-logged soils uninhabitable by most other woody plants. Plants of *A. maritima* ssp. *oklahomensis* installed at the Utah Botanical Center did not survive in this study, even in wet soils under moderate to full sun. This taxon may tolerate full sun only in humid air, and irrigated plants may need to be shaded in the climate of the Intermountain West.

In contrast to the previously cited study (14), shade seemed to play a protective role in prolonging survival of *A. maritima* ssp. *oklahomensis* planted at the Utah Botanical Center (Fig. 2; Table 3), especially for those installed at the native site, the only site with live transplants four weeks after bud break (Table 1). Transplants closest to the pond at the Utah Botanical Center pond site also gained some protection from mortality, although it is unclear whether this was due to partial shading from neighboring plants or to growth in wetter soils (Table 3). Some transplants at the Utah Botanical Center tree/turf site also were partially shaded, and therefore avoided prolonged periods of high light, but this did not spare them from early mortality (Tables 1 and 3), and all transplants at this site suffered some degree of damage early in the growing season (Table 1).

Although the effects of light and soil moisture on progression of bud break and leaf scorch were difficult to separate in this observational study, the fact that transplants survived four weeks later at the native site, where prolonged high light was not a factor and soils were dry [ $< 10\%$  water by volume at a depth of 20 cm (8 in)], suggests that protection from high light was an important contributor to plant survival. Schrader and others (13) demonstrated that *A. maritima* can be grown on soils with  $< 10\%$  water by volume [at a depth of 6 cm (2.4 in)] in Ames, IA, with permanent wilting in 20 to 90% of leaves, but no death attributable to water deficit. How long these plants would have survived under those conditions is unknown, and differences exist in climatic conditions between northern Utah and central Iowa. Relative humidity ranged from 40 to 82% in the cited study conducted in Iowa; relative humidity averaged only 35% during the 2007 spring growing season at the Utah Botanical Center, and was below 20% for days at a time, with few precipitation events (data not shown). Further, evapotranspiration ( $ET_o$ ) exceeded precipitation between November 2006 and May 2007, with precipitation  $\div ET_o$  averaging 0.52 (Table 1), and it continued this way for the remainder of the growing season (data not shown). By definition, this means that the climate of this region in northern Utah was similar to a desert climate (no period during the year with three consecutive months having mean precipitation  $\div ET_o > 0.6$ ) (5). Arid climates also are characterized by a lack of clouds and, thus, high solar radiation. Full sun was measured at  $1,780 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  PAR at 1100 h at the Utah Botanical Center on the day of data collection (April 2, 2007), whereas mean PAR at the same time of day during the sun treatment in the *Alnus* shade tolerance study (June through September) was only  $1,557 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  (14).

The increasing variability of occurrence of leaf scorch at higher light intensities on the correlation curve (Fig. 2A) suggests that light may be only one factor in the decline of *A. maritima* ssp. *oklahomensis* plants at the Utah Botanical Center. It is likely that low relative humidity, sparse precipi-

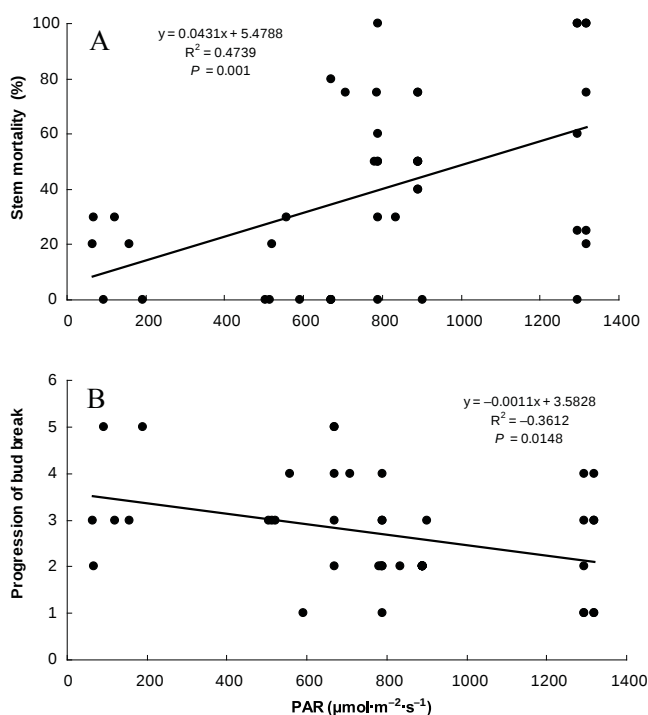


Fig. 2. Correlation between light intensity, measured as photosynthetically active radiation (PAR), and leaf scorch and bud progression rating. Measurements were taken on April 4, 2007. Leaf scorch was recorded as a percentage of total leaf area. Spring bud progression was recorded using a 5-point rating system: 1 = no bud break, 2 = moderate bud break, 3 = substantial bud break, 4 =  $< 50\%$  of leaves fully expanded, 5 =  $\geq 50\%$  of leaves fully expanded.

tation, and high solar radiation contributed to lethally high evaporative demand on expanded leaves of this taxon during this study. Progression of bud break was greatest at the pond site under conditions of wet soil and low to moderate light (Table 3). Leaves that expanded in high light, despite the fact that they were on plants in wet soil, quickly succumbed to drying conditions, and all transplants in all three sites eventually died. In the greenhouse, seeds of *A. maritima* ssp. *oklahomensis* germinated in soils from the three northern Utah sites, and germination and seedling survival rates were similar in the three soils (Table 2), so it is unlikely that differences in soil characteristics could account for mortality differences at these sites. Transplants at the native site may have survived even longer than they did had they been irrigated, because no transplants at this site were exposed to high light. This possibility is supported by our observation that plants from the same crop held on an irrigated gravel pad at the Utah State University Greenville research farm had to be transferred from full sun back to a partly shaded location to avoid leaf sunburn and scorch, despite the fact that plants were irrigated twice daily by pop-up sprinklers.

This study represents the first test of *A. maritima* ssp. *oklahomensis* performance in the climate of the Intermountain West, and it suggests limits to the adaptability of this taxon in areas with a combination of low relative humidity, dry soils, and intense solar radiation. This should not deter efforts to bring this species into ornamental use in Utah landscapes, however, because our observations suggest plants of this taxon are capable of thriving in this climate in protected, irrigated sites under partial shade. Further, its tolerance to extended periods in water-logged soils can be an asset in areas where flood irrigation is an economical means of providing water to managed landscapes. Future studies should focus on determining the impact of low relative humidity and high solar radiation, under conditions of decreasing soil moisture, on gas exchange and chlorophyll fluorescence parameters in this taxon, with the goals of identifying its limits of climatic adaptation, and determining appropriate management strategies for its potential use in constructed Intermountain West landscapes.

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