Beargrass

Xerophyllum tenax

ABSTRACT

Through a greenhouse experiment, we found that smoke-water can be an effective restoration tool in germinating beargrass (Xerophyllum tenax (Pursh) Nutt. [Liliaceae]) seeds. We studied the effects of smoke-water on germination rates of beargrass seeds collected from low-elevation dry forests of the southeastern Olympic Peninsula of Washington State and from a wetland of the western Peninsula. Seeds received a treatment of either smoke-water or tap water (the control), which was followed by a cold stratification treatment for 0, 8, 10, 12, 14, or 16 wk. The highest success of beargrass seed germination resulted from seeds collected from the wetland habitat being exposed to smoke-water prior to undergoing 14 wk of cold stratification. This study supports the use of smoke technology in restoration when the reintroduction of burning is not feasible.


KEY WORDS
fire, seeds, Olympic Peninsula, restoration, Liliaceae

NOMENCLATURE
USDA NRCS (2008)

Figure 1. Beargrass in bloom at the Quinault site. Photo by Daniela J Shebitz

Beargrass (Xerophyllum tenax (Pursh) Nutt. [Liliaceae]) is an herbaceous perennial that grows 1 to 2 m (3.3 to 6.6 ft) in height (Maule 1959; Rose and others 1998). It ranges across 914 m (3000 ft) of elevation from near sea level on the Olympic Peninsula of Washington State to subalpine forests in the Cascades, Olympics, Sierras, and Rocky Mountains (Hitchcock and Cronquist 1973; Stewart 1994; Cooke 1997; Blatner and others 2004). From May to late summer, beargrass flower stalks grow to 150 cm (60 in) tall and are topped with a club- or cone-shaped inflorescence of white flowers, each approximately 1.3 cm (0.5 in) across (Figure 1) (Cooke 1997; Munger 2003). Flowering occurs in 5- to 7-y intervals (Stewart 1994; Munger 2003), and studies indicate that increased flowering often occurs following fire (Cooke 1997; Kruckeberg 2003). Beargrass’ structural adaptations to fire are exemplified in its apical meristem, leaves (Rentz 2003), and rhizome (Maule 1959), yet the response of its seeds to fire has not yet been investigated.

Past research has shown that it is difficult to germinate beargrass seeds under controlled conditions using hot water, freezing, chlorine bleach, or acid (Smart and Minore 1977; Jelitto and Schacht 1985). The only method that has proved successful for high-elevation beargrass seeds involves long periods (16 wk) of cold stratification (Smart and Minore 1977).
Through this study, we aim to determine if the germination of beargrass seeds collected from 2 restoration sites on the Olympic Peninsula lowlands can be enhanced through exposure to smoke. We introduce a method for creating aqueous extracts of smoke, or “smoke-water,” which is similar to that initiated by de Lange and Boucher (1990) yet is easily accomplished in one’s backyard. This treatment is compared with a control of tap water that has not been infused with smoke.

LOW-ELEVATION BEARGRASS HABITATS AS FIRE-ADAPTED ECOSYSTEMS

The Olympic Peninsula and southwestern Puget Trough of Washington State have a glacial history and a subsequent environmental and cultural history that created suitable conditions for beargrass, typically a subalpine species, to inhabit low elevations. Many forests of the Olympic Peninsula lowlands in which beargrass currently grows were historically maintained as open-canopied systems through anthropogenic burning conducted by Native Americans (Peter and Shebitz 2006; Shebitz and others 2008). Frequent, low-intensity fires ensured the presence of prairie and savanna flora and fauna that were integral components of diets, medicines, baskets, and rituals of local tribes (Norton 1979; LaLande and Pullen 1999; Peter and Shebitz 2006). Beargrass, a fundamental basketry plant of Olympic Peninsula tribes, is one example of a species that benefited from the anthropogenic burning.

Fire has long been used by Native Americans throughout the western US to enhance beargrass growth to ensure its availability for use in basketry (Hunter 1988; LaLande and Pullen 1999; Rentz 2003). Anthropogenic and natural fires have been suppressed, however, since the establishment of reservations and the allotment of tribally owned land in the mid- to late-1800s (Norton 1979; Boyd 1999; Peter and Shebitz 2006). These systems have therefore undergone complete succession, leaving no intact example of beargrass savannas or prairies in the southeastern or western Olympic Peninsula. A decline in low-elevation beargrass was quantified over a 17-y period due, in part, to the suppression of fires and subsequent increase in canopy cover over the past century (Shebitz and others 2008).

RESTORATION SITES

To conserve beargrass and restore its habitat on the Peninsula, the Olympic National Forest (ONF) staff and the Skokomish and Quinault Indian Nations are making efforts to reintroduce anthropogenic burning. The research presented in this article will assist in understanding effects of fire on beargrass seed germination so that information gained may eventually be used to reintroduce beargrass to restoration sites.

Seeds were collected on 2 research sites; one on the southeastern Peninsula (elevation 200 m [656 ft]), the other on the western Peninsula (elevation 100 m [328 ft]). The southeastern restoration site is in the ONF’s Skokomish River Basin, near the Skokomish Reservation in a low-elevation *Pseudotsuga menziesii* (Mirb.) Franco (Pinaceae) (Douglas-fir) forest. Annual precipitation is 226 cm (89 in) (USDA NRCS 1999). Although some beargrass persists in this area under a canopy, it is not as prolific as it was historically (Shebitz 2005; Shebitz and others 2008). Prior to European contact, this seed collection site was an anthropogenically maintained savanna with beargrass as a dominant component (Peter and Shebitz 2006).

The western restoration site is on the Quinault Reservation in a *Sphagnum* bog that experiences seasonal flooding and drought (Kunze 1994). A unique feature of the site is the presence of camas (*Camassia quamash* (Pursh) Greene var. *azurea* (A. Heller) Gould [Liliaceae]). Camas was traditionally a fundamental food crop for western Washington tribes, including the Quinault (Gunther 1974), and maintaining an open habitat for camas was a primary reason for burning in the Pacific Northwest (Boyd 1999). Camas, therefore, is an indicator that the area was historically open-canopied (Antieau and Gaynor 1990). It is believed that this wetland was part of the Quinault annual migration route (James 2003), and it was likely burned when it was seasonally dry in the fall. Despite its occurrence in the temperate rainforest zone, Kulzer and others (2001) suggest that, “[f]ire may be an important factor in the formation and persistence of this [habitat].”

Restoration efforts have been initiated at both the southeastern ONF and western Quinault Reservation sites; however, reintroducing a pre-European settlement fire regime is not feasible due to budgetary constraints. In this study, the role of smoke in germination is investigated so that despite the inability to conduct large-scale burns on a regular basis, beargrass seedlings could potentially be introduced to the sites after being germinated using techniques described below.

METHODS

The greenhouse study was designed to determine if smoke-water can be used to enhance germination rates of low-elevation beargrass and to decrease length of time needed in stratification (cold, moist conditions). Research with high-elevation beargrass (Smart and Minore 1977) found that 14 to 16 wk of stratification was required, but no published work has been conducted with low-elevation beargrass seed germination. After a preliminary greenhouse experiment, we determined that without smoke-water, low-elevation beargrass requires a minimum of 8 to 12 wk of stratification.
Mature beargrass seeds were harvested in August 2004 within 200 m (656 ft) of the restoration units in both the Quinault and ONF locations. In order to minimize experimental variance, we harvested seeds by hand from 20 individual beargrass inflorescences, on the same day and from plants located within a half acre of each other in both sites. Seeds were counted, divided into packets of 50, and stored in the Miller Seed Vault at the Center for Urban Horticulture, University of Washington, at 15 °C (59 °F) and 20% humidity, until needed.

Half of the seeds used in this experiment were exposed to smoke-infused water and the others were exposed to tap water as the control. The smoke-infused water was created from species associated with both of the vegetative communities at both Quinault and ONF restoration sites: Gaultheria shallon Pursh (Ericaceae) (salal), Polystichum munitum (Kaulf.) C. Presl (Dryopteridaceae) (swordfern), Thuja plicata Donn ex D. Don (Cupressaceae) (western redcedar), Douglas-fir, and beargrass. A charcoal grill was used to make the smoke-infused water. Charcoal was burned on half of the base of the grill, and freshly collected vegetation was placed directly above it on the upper grill surface. A pan of water was on the opposite side of the upper grill surface. The grill was covered for 2 h as the coals burned the vegetation, and smoke infused the water in the pan. The water did not reach the boiling point. Once the smoke-infused water cooled, 200 ml (6.8 oz) were poured into each glass container and 50 beargrass seeds were added. An air pump and stone were then used to circulate the water (with seeds added) for 24 h. The control treatment involved beargrass seeds added to tap water and electrically circulated for 24 h.

After the seeds were treated, they were sown in nursery flats measuring 53.3 cm x 26.7 cm (21 in x 10.5 in). These flats were prepared by adding a seeding mix (Terra-Lite Redi-Earth, Scotts-Sierra Horticultural Products, Marysville, Ohio) and then dividing the flats into 8 quadrats measuring 13.3 cm x 13.3 cm (5.2 in x 5.2 in) using a plastic-lined barrier between the smoke-water and control treatments to discourage leaching between treatment soils. Seeds from the ONF and Quinault sites were randomly sown into a quadrat. The smoke-infused water and tap water were added to the flats with the beargrass seeds, and the flats were watered and covered with plastic before going into stratification or the greenhouse.

The seeds then underwent stratification for 0, 8, 10, 12, 14, or 16 wk. The flats testing the effects of smoke-water and tap water with 0 wk in stratification were placed directly in a greenhouse at 26 °C (79 °F). Those going into cold stratification for a designated period of time were stored in a chamber at 5 °C (41 °F) and were then moved into the greenhouse. Each treatment was replicated 4 times with 50 beargrass seeds per replicate. Therefore, a total of 12 treatments were used for both of the restora-
Data Analysis

Our study objectives were to determine if seeds being exposed to smoke-water resulted in increased germination rates and (or) influenced the seeds’ response to increased length of stratification. The germination rates of seeds from the 2 sites were significantly different ($P < 0.001$), so the data for each were analyzed separately. A two-way analysis of variance (ANOVA) incorporating the treatment and length of stratification was performed using SAS version 9.1 (SAS 2003). Statistical significance throughout this paper is defined with $\alpha = 0.05$.

RESULTS

The earliest germination occurred after 10 wk in stratification. The greatest germination rates for the Quinault seeds (41%) occurred after being soaked in smoke-water and then undergoing 14 wk of stratification. The ONF seeds did not have as many germinants as the Quinault seeds for either treatment.

The smoke-water treatment generally resulted in greater seed germination for both the west and east sites for each respective length of stratification. For Quinault (Figure 2) and the ONF (Figure 3), seed germination for the smoke-water and control treatments reached a peak after 14 wk of stratification but this rate was not significantly different from the slightly lower rate observed after 16 wk in cold stratification for the ONF’s smoke-water ($P = 0.793$) or water treatment ($P = 0.661$) and Quinault’s smoke-water ($P = 0.793$) and water ($P = 0.786$) treatments.

Overall, seeds treated with smoke-water prior to stratification had the higher germination rates. For seeds harvested from the Quinault site, smoke-
water resulted in a significant increase ($P = 0.017$) in seed germination over the control. For the ONF site, smoke-water did not result in a significant change ($P = 0.410$) over the control (Table 1). Neither the Quinault nor ONF site have significant interactions of the smoke-water versus tap-water treatment and length of stratification ($P = 0.681$, $P = 0.742$, respectively).

**DISCUSSION**

Increased beargrass seed germination resulting from exposure to smoke-water suggests that beargrass seeds have evolved germination strategies that respond to chemical cues associated with fire. Since de Lange and Boucher (1990) first published the stimulatory effects of plant-derived smoke on seed germination, more than 70 compounds in smoke, such as ethylene and ammonia (van de Venter and Esterhuizen 1988) and nitrogen dioxide (Keeley and Fotheringham 1997), have been studied as potential germination triggers (Malakoff 1997). Flematti and others (2004) identified butenolide 3-methyl-2H-furo[2,3-c]pyran-2-one as a compound present in plant- and cellulose-derived smoke that promotes germination of a variety of smoke-responsive taxa similarly to that of plant-derived smoke-water. Determining the particular chemical that beargrass is responding to is beyond the scope of this study.

Seeds collected in different locations may have germination responses that vary with environmental attributes of the collection site, such as elevation, soil moisture, and temperature (Baskin and Baskin 2001). The beargrass seeds of the xeric, well-drained forest soils of the southeastern Peninsula did not have a significantly different response between the smoke-water and water treatments. The region from which the seeds were harvested received approximately 226 cm (89 in) of precipitation per year, as opposed to the more than 305 cm (120 in) of rain received by the Quinault site (Henderson and others 1989). Previous research has shown that plants of different populations of the same species often have seeds that differ in their sensitivity to substrate moisture (Pollock 1974; Baskin and Baskin 2001). It is possible that the reason there was not a significant difference between the smoke-water and tap-water treatments for the seeds from the ONF site is that the seeds were more sensitive to the increase in moisture. Meaning that, water is more of a limiting factor in the ONF habitat than in the Quinault site, which typically has moist soils throughout much of the year.

Although not statistically significant, the seeds from the ONF did have a higher germination rate when exposed to smoke-water (15.25% overall) than when exposed only to water (13.13%) prior to stratification. Germination for each period of stratification from 10 to
16 wk was greater in the smoke-water treatment than in the tap-water treatment, except for 14 wk when the treatments had an equal response of 22%. It is likely that increasing the number of replicates in this study would contribute to a more significant response to the smoke-water.

It is important to determine whether the type of plant material and species burned has an influence on beargrass seeds’ germination response to smoke. We do not know how much of the active substance occurs in the soil after a fire, or how long seeds or soil need to be exposed to smoke to elicit a response (Brown 1993). Although in this experiment harvested beargrass seeds responded to smoke, it is unclear whether germination would be influenced if the seeds were still in the soil seedbank. Roche and others (1997) found that some species respond only to smoke application to the soil seedbank and not to the application of smoke to freshly collected seeds. The authors suggest that some seeds need to enter the soil seedbank before they are receptive to the germination-promoting effects of smoke.

Experiments performed by Keeley and Fotheringham (1998) on 34 chaparral species found that the amount of exposure time required for germination was species-specific. In some cases burial for 1 y or stratification are required in addition to smoke exposure, and others required both heat and smoke treatments. All of these factors can have an effect on germination and should be considered when using smoke or chemicals in smoke to induce germination.

An alternative explanation for increased germination rates following exposure to smoke-water created in the manner presented in this paper is that the charcoal in the grill provided the stimulatory effects for germination. To ensure that the beargrass was responding to the smoke, one might conduct this experiment using woody vegetation from its habitat. Regardless of whether beargrass seeds responded to the smoke or to the charcoal, what is important is that this research presents a means to increase beargrass seed germination rates.

Implications of This Research
Knowledge of smoke-water as a seed germination strategy has potential implications for the conservation of low-elevation beargrass and for the management of the savannas of which it is a part. This study shows that harvested beargrass seeds from the low-elevation restoration sites have high germination rates when exposed to smoke-water, and that an increase in germination can be achieved when seeds are exposed to any water, smoke-infused or not.

Although the germination of beargrass seeds, particularly from the western Olympic Peninsula, was stimulated by smoke-water in the greenhouse, smoke’s role in germination ecology cannot be fully understood until its compounds are tested in the field (Baskin and Baskin 2001). Under field conditions, however, it will not be easy to isolate the effects of smoke from other chemical and physical effects such as ash deposition, charred wood, heated soil, and plant competition removal.

Based on this research, we suggest soaking low-elevation beargrass seeds for 24 h in smoke-water prior to sowing the seeds and exposing them for 14 wk in stratification. An appropriate follow-up study would research the survival of beargrass seedlings germinated through both smoke-water and tap-water treatments after being outplanted into the restoration sites. Based on findings presented in this paper and a future transplant study, the restoration potential of beargrass by seedlings will be better understood in low-elevation beargrass habitat. Such knowledge can be extremely pertinent, particularly for planting beargrass in fire-adapted habitats where it is not feasible to reintroduce fire directly, such as the two restoration sites used in this study.

CONCLUSIONS
The germination rates in this study were lower overall for beargrass seeds from the dry, eastern Olympic Peninsula restoration sites than from the wet, western Peninsula site. For beargrass seeds collected from low-elevation xeric sites, a smoke-water treatment generated high germination rates, yet similar results arose from soaking the seeds in water that had not been infused with smoke. The highest success of beargrass seed germination as found in this study resulted from seeds collected from the wetland habitat being exposed to smoke-water prior to undergoing cold stratification. Based on this study’s findings, therefore, smoke-water can be an effective restoration tool in germinating beargrass, particularly for wet, low-elevation sites.

ACKNOWLEDGMENTS
We gratefully acknowledge the assistance of Justine E James Jr from the Quinault Indian Nation for his assistance in gathering seeds and sharing his knowledge of beargrass with us. This research was completed with the assistance of Kean University’s Untenured Faculty Research Initiative.

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AUTHOR INFORMATION

Daniela J. Shebitz
Assistant Professor
Kean University
College of Natural, Applied, and Health Sciences
Institute of Urban Ecosystem Studies
1000 Morris Avenue
Union, NJ 07083
dshebitz@kean.edu

Kern Ewing
Professor
University of Washington,
College of Forest Resources
Center for Urban Horticulture
Box 354115
Seattle, WA 98115
kern@u.washington.edu

Jorge Gutierrez
Recent Kean University graduate, currently at Temple University