Daniela Joy Shebitz[1], Kean University Biology Department, 1000 Morris Ave. Union, New Jersey 07083

Sarah Hayden Reichard, University of Washington, College of Forest Resources, Seattle, Washington 98195

and

Wolde Woubneh, Kean University Mathematics Department, 1000 Morris Ave. Union, New Jersey 07083

Beargrass (*Xerophyllum tenax*) on the Olympic Peninsula, Washington: Autecology and Population Status

Abstract

We studied the autecology and population status of beargrass (*Xerophyllum tenax* (Pursh) Nutt.) on the Olympic Peninsula of Washington State, focusing in the Olympic National Forest (ONF). Objectives were to: (1) define and describe beargrass habitat types in the ONF through an exploratory field study, and (2) determine whether beargrass populations in the ONF have declined where the species was historically present. We found three distinct beargrass habitat types in on the ONF: western low elevation, eastern low elevation, and high elevation habitats. These habitat types significantly differ in elevation, slope, topographic moisture, vegetation cover, successional stage, and litter layer thickness. We suggest environmental conditions of these habitat types may be attributed to the glacial and cultural history of the Olympic Peninsula. Beargrass cover in previously established plots on the southeastern Olympic Peninsula declined over the past 17 years, perhaps due to harvesting for the floral industry and an increase in canopy cover due to the absence of natural and anthropogenic burning. Our methods and findings may apply to other Northwestern species.

Introduction

Beargrass *(Xerophyllum tenax* (Pursh.) Nutt.) (Figure 1) is an evergreen, perennial herb in the Melanthiaceae, Liliales (Rudall et al. 2000, Vance et al. 2004) that grows in large, dense clumps or tussocks (Cooke 1997, Higgins et al. 2004). Basal leaves grow densely in a cluster close to the ground, can be up to 60 cm long and 5-10 mm wide at the base, and gradually taper to a narrow and stiff tip (Maule 1959, Henderson et al. 1989). Beargrass reproduces both vegetatively by rhizome, and sexually by seed.

Flowering occurs in 5-7 year intervals (Stewart 1994, Munger 2003) and it has been suggested that maximum flowering may be linked to fire (Cooke 1997, Kruckeberg 2003). Vance et al. (2004) found that beargrass flowers are self-incompatible and attract a broad range of pollinators from the insect orders Diptera, Coleoptera, and Hymenoptera.

Beargrass inhabits mixed-coniferous forests and meadows in the mountains of west-central California up to northwestern Washington, and from Yellowstone National Park north to southwestern Alberta and southeastern British Columbia (Maule 1959, Higgins et al. 2004). The species' habitat ranges in elevation from sea level on the Olympic Peninsula to over 2,300 m in the Rocky Mountains (Hitchcock and Cronquist 1973, Stewart 1994, Cooke 1997, Higgins et al. 2004). Beargrass often grows in subalpine meadows or as a dominant understory component of dry, mixed-coniferous forests (Pojar and Mackinnon 1994, Higgins et al, 2004, Kruckeburg 2003), where it occurs in highest densities under canopy openings (Crane 1990).

In addition to being a significant component of various ecosystems throughout the northwestern United States, beargrass has cultural and commercial importance in the region (Higgins et al. 2004, Vance et al. 2004). Native Americans of California and the Pacific Northwest (PNW) value beargrass as a fundamental basketry material (Rentz 2003, Vance et al. 2004, Shebitz 2005). Interviews with members of the Quinault and Skokomish Indian Nations on the Olympic Peninsula have revealed concern that commercial harvesters are negatively affecting beargrass populations by not selectively harvesting leaves (Nordquist and Nordquist 1983; Shebitz 2005) Indeed, some floral greens wholesalers consider it to be the highest volume European import of all non-timber forest products (Thomas and Schumann 1993). Between 1999 and 2001,

[1]Author to whom correspondence should be addressed: Dr. Daniela Shebitz. E-mail: dshebitz@kean.edu

Figure 1. Beargrass in bloom on the Quinault Reservation.

over 422,000 pounds of beargrass leaves were collected from PNW forests (Kramer 2001), and a decade ago, the market potential for beargrass was estimated at over $US 1 million for thousands of tons of leaves (Blatner and Schlosser 1997).

Despite its wide range and the interest in beargrass as a non-timber forest product, minimal research has been conducted on the species. In particular, its autecology in the Olympic National Forest (ONF) of Washington State is largely unstudied.

Exploratory Study of Beargrass on the Olympic Peninsula

Throughout its range, beargrass predominately occurs in subalpine meadows. On the Olympic Peninsula, however, it also inhabits low elevation dry forests and clearings on the east side of the Olympic Mountain Range and bogs and moist forests on the west side. Quantitative studies involving beargrass have for the most part taken place in high elevations (Maule 1959, Crane 1990, Higgins et al. 2004, Vance et al. 2004).

The primary objective of this study was to gain an understanding of beargrass in the ONF and environmental variables that characterize its habitat. Based on preliminary observation and Henderson et al.'s (1989) *Forested Plant Associations of the Olympic National Forest,* we hypothesized that there are three distinct types of beargrass habitats in the ONF: low-elevation eastern Peninsula, high elevation, and low-elevation western Peninsula. A secondary objective of the field study was to determine if the cover of beargrass is changing in areas where it was historically present in the ONF. After presenting our results, we interpret the current distribution and population trends of beargrass on the Olympic Peninsula.

Methods

The Study Site: Olympic National Forest

The Olympic Peninsula in western Washington is ca.1.7 million ha (Wood 1976), with ONF consisting of about 260,382 ha from sea level to ca. 2,174 m (Henderson et al. 1989). The climate varies from very wet, humid, and maritime along the western coast, to dry in the rainshadow northeastern corner. Vegetation is influenced by the maritime climate, resulting in dense forest canopy over much of the landscape. The dominant late successional tree species are western hemlock (*Tsuga heterophylla*) and silver fir (*Abies amabilis*), and the dominant seral tree species is Douglas-fir (*Pseudotsuga menziesii*). The upper elevational limit of forests (timberline) occurs at ca. 1,615 m in wetter environmental zones to over 1,890 m in the rainshadow (Henderson et al. 1989).

Henderson et al. (1989) classify Peninsula vegetation patterns into zones. The Western Hemlock Zone (dominated mostly by Douglas-fir) and Sitka Spruce (*Picea sitchensis*) Zones occur at the lower elevations. The Douglas-fir Zone occurs sporadically on dry microsites. The Mountain Hemlock (*Tsuga mertensiana*), Silver Fir and Subalpine Fir (*Abies lasiocarpa*) Zones are higher in elevation.

Field Methods

The sampling technique for this study was based on research conducted by Henderson et al. (1989) since 1975 to characterize the forested plant associations of the ONF. The authors established ca. 1,500 plots randomly throughout the ONF, 400-600 of which were intensively studied. The circular, fixed-area 0.04-0.08 ha intensive plots were used to help analyze the environmental and

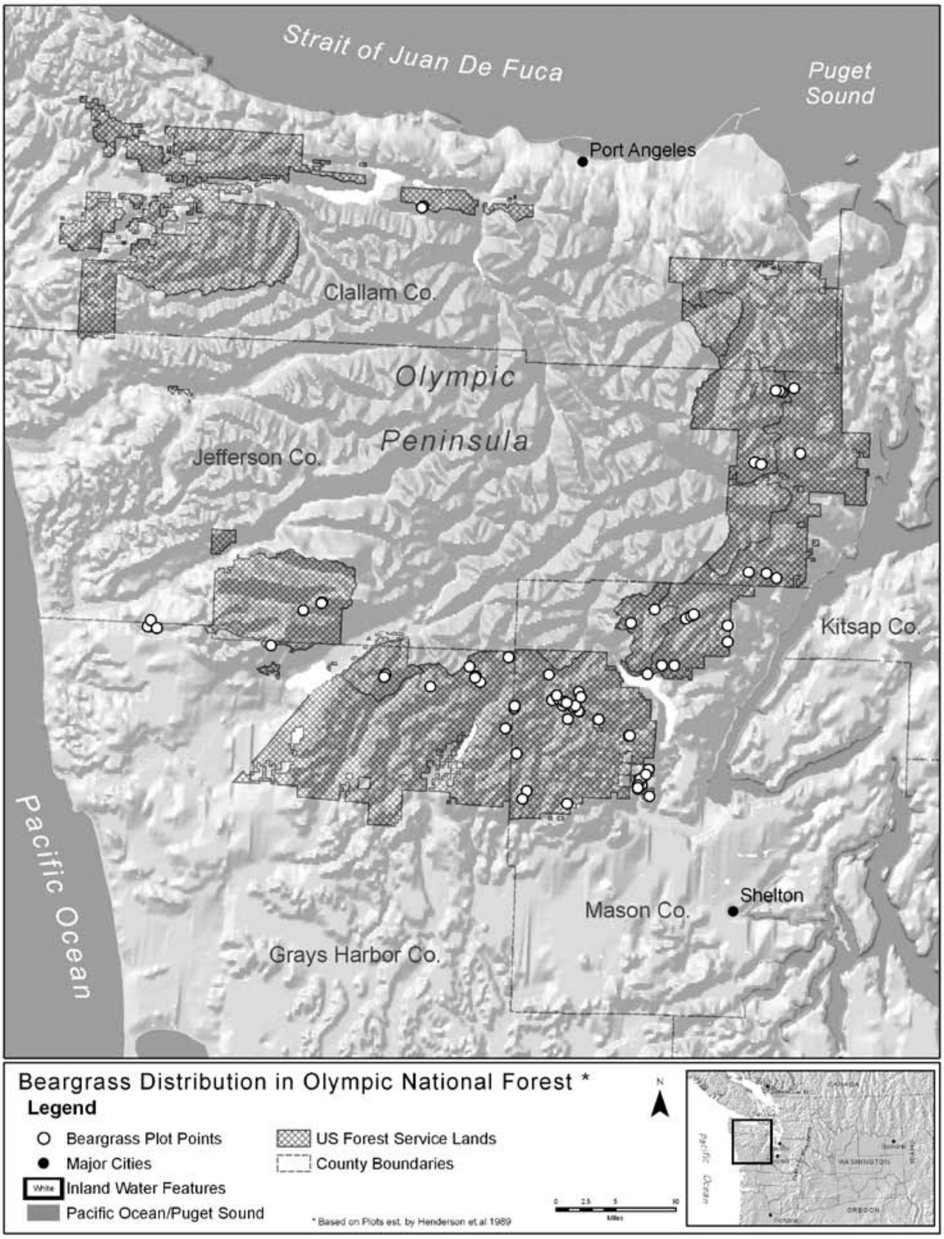

Figure 2. A map illustrating beargrass distribution in the Olympic National Forest based on plots established by Henderson et al. (1989).

biological relationships of each plant association. Within these plots, each tree was numbered with spray paint on the trunk and marked with metal tags at the base. Henderson and others provided their original data on environmental variables and the percent cover of species for each plot. Eighty-four of the intensively studied plots had beargrass (Figure 2). We calibrated our methods with the original study by working with Jan Henderson, Robin Lesher, and David Peter to re-establish some of their original plots.

In the summer of 2003, we attempted to resample 46 of the 84 intensively sampled plots that had beargrass. The plots were chosen based on accessibility (some roads had been decommissioned since original plot installation) and steepness of slope (limiting sampling to 70% or less). Using aerial photographs of the original plot locations, maps illustrating the location, and coordinates taken from aerial photographs, 28 of the original plots were successfully relocated and sampled using the original plot centers. These ranged in elevation from 110 to 1,024 m above sea level. Of the 28 plots resampled in 2003, 11 were originally established and surveyed in 1986, 11 were from 1993, and 6 plots were from 1998 (Figure 3). By resampling the same plots established 5-17 years prior, it was possible to determine changes in environmental variables such as canopy cover of the overstory and understory, successional stage, and percent cover of beargrass.

We were unable to find the exact plot center in 18 sites either due to logging activities since original plot establishment, difficulties in finding the trees that were spray painted due to time elapsed since marking, or discrepancies with the given coordinates and directions. In 17 of those sites, although we were unable to find the original plot center, beargrass was present in the vicinity. Therefore, a new plot was installed using Henderson et al.'s (1989) technique in locations that were as close to the original plot area as was possible to determine. We were unable to determine our proximity of these plots to the original plots. Information from these plots was not used for comparisons to the original environmental variables, but assisted in understanding beargrass ecology in the sampled areas. For one site, neither beargrass nor the original plot center could be found so the vegetation was not sampled (Figure 3).

Techniques for data collection used in this study are described by Henderson et al. (1989) and Henderson and Lesher (2003), but briefly discussed in Table 1. In addition, we developed methods for measuring beargrass at each site.

Measurements on beargrass

The percent cover of beargrass was estimated in all plots. In addition, five individual beargrass tussocks were randomly selected in each plot.

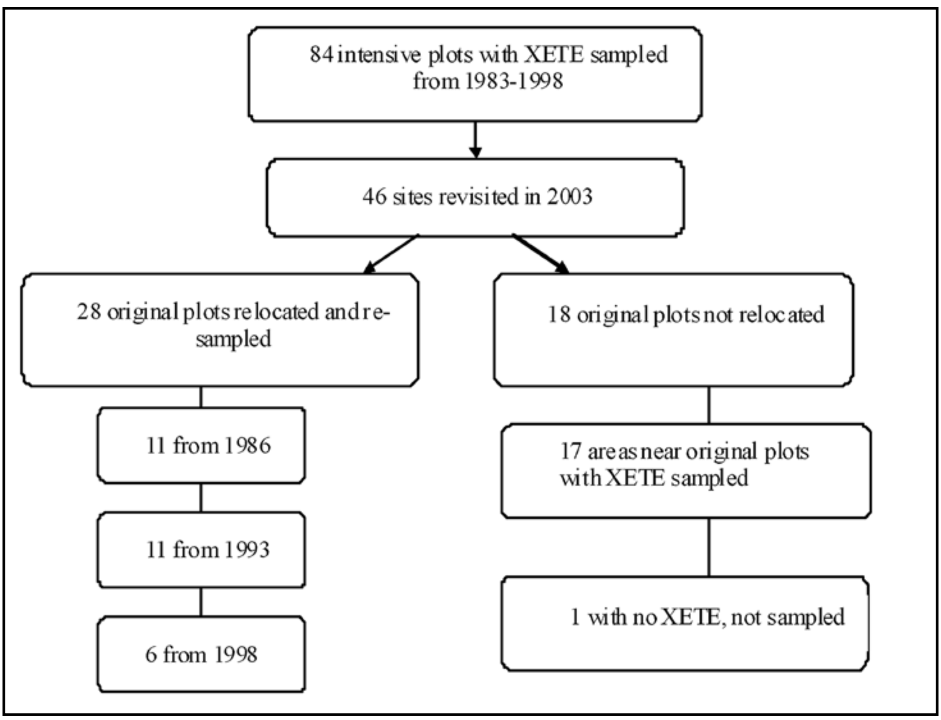

Figure 3. A flow diagram illustrating original plots sampled with beargrass, success of relocating sites in 2003. Those 28 plots relocated are used in comparative tests over time. All 45 sampled plots are used in defining beargrass habitat types. XETE = beargrass (*Xerophyllum tenax*).

TABLE 1. Environmental attributes measured at each survey site and the methods employed based on Henderson et al.'s (1989) techniques

Environmental Attribute	Methods
Elevation	Measured at plot center using a GPS (Magellan SportTrek®).
Aspect	The compass direction (using true north) of the downward slope at plot center.
Slope	The upslope and down slope of the steepest angle (in percent) taken using a clinometer at plot center and averaged.
Topographic Moisture (TM)	A scale of 1-9 where 1 is driest microsite conditions caused by a very steep slope or convex slope position. TM of 9 is represented by open water.
Crown Cover (CC Over)	Percent canopy cover, ocularly estimated (0-100%) .
Understory Crown Cover (CC Under)	Percent cover of shrubs and herbs in the plot. (0-1% estimated to the nearest tenth, 10-90% to the nearest five percent, and 1-10% and 90-100% to the nearest percent).
Successional Stage	A scale of 1-9 where 1 is a forest in early stages of development following disturbance and 9 represented a climax forest.
Vegetation Zone	Named based on dominant tree species in each plot from Henderson and Lesher (2003).
Plant Association	Numeric code from Henderson and Lesher (2003).
Regolith	The regolith is the loose unconsolidated rock material that overlies the bedrock. Regolith class was assigned a code using Henderson and Lesher (2003).
Bedrock	Numerical code for the dominant type of rock underlying the regolith taken from Henderson and Lesher (2003).
Litter Depths	Four measurements (cm) taken 9m from plot center (along the cardinal directions) and averaged.
Soil Texture	Four samples of soil surveyed by touch taken 9m from plot center (along the cardinal directions).
Percent Cover of Each Species	For each tree, shrub, and herb species present, the total percent cover in the plot was estimated.

The height of each individual was determined by measuring the distance from the ground surface to the crest of the leaves. Additionally, we measured the widest diameter of foliar crown material (W1), and the diameter perpendicular to this (W2). Elliptical crown area was calculated using the following formula:

$$\text{Area} = (W1 * W2 * 3.142)/4$$

(from Pendergrass et al. 1999).

The length and width of five randomly-selected beargrass leaves and the percent cover of each species that occupied the plants' vertical space were also recorded.

Data Analysis

A Principal Components Analysis (PCA) was conducted using PC-ORD (Version 4.25 McCune and Mefford 1999) to classify distinct habitat types of beargrass, using environmental variables as the main matrix and overlaying a matrix of vegetation. Axes 1 and 2 generated using PC-ORD were then incorporated into SigmaPlot (1992) to generate a figure (Figure 4) of the relative distribution of sampled sites.

Pearson Correlation Coefficients were calculated using the PROC CORR procedure on SAS version 9.1 (SAS 2003) to determine which environmental variables were correlated. Habitat types were distinguished by analyzing for significant differences due to location parameters between the distinct habitat types' environmental attributes using a fixed one-way Analysis of Variance (ANOVA) on SAS version 9.1 (SAS 2003). The location of the plot (designated 1, 2, or 3 based on the PC-ORD) was the independent variable (α = 0.05). The Duncan multiple range test post-hoc procedure was conducted. Descriptive statistics were used to assist in describing environmental characteristics that define the habitat types.

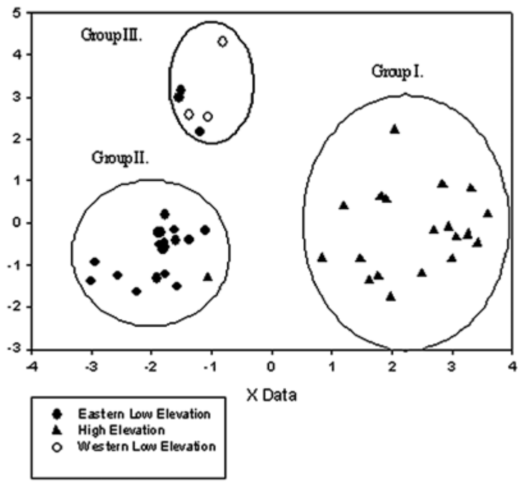

Figure 4. Distribution of sites along the first two axes of the ordination.

For sites in which the original plot center was relocated from Henderson et al.'s (1989) study, paired t-tests were performed to compare current and past measurements of beargrass percent cover, canopy cover of the overstory and understory, and successional stage. The pairs of current and past plot measurements were grouped according to the date of original plot establishment: 1986, 1993 and 1998.

Results

Habitat Types

Three distinct beargrass habitat types were evident from an ordination of the environmental attributes from the surveyed sites (Figure 4). Component 1 of the ordination (X Data) had an eigenvalue of 4.577, which explained 41.606% of the variance. The measured environmental factors with the greatest positive weightings (eigenvectors) on Component 1 were elevation (0.4347), slope (0.3770) and vegetation zone (0.3467) while the greatest negative weightings were regolith (-0.4424) and bedrock (-0.4196). Component 2 of the ordination (Y Data) had an eigenvalue of 1.986, which explained 18.058% of the variance. The most influential factor loadings of Component 2 were negative and included successional stage (-0.5971), canopy cover of the overstory (-0.5840), and understory cover (-0.3839). Aspect (0.2758) had the greatest positive weighting.

Based on the general location of the study sites, we have named the habitat types: high elevation, eastern low elevation, and western low elevation. The three habitat types had numerous abiotic and biotic differences (Table 2).

We found that some of the environmental variables were positively correlated (n=45). Elevation was positively correlated with slope (r=0.7827), and the successional stage was correlated with the canopy cover of the overstory (r=0.6088) and elevation (r=0.3094). The beargrass characteristics of height was correlated with leaf width (r=0.8546), and leaf length (r=0.7687) and beargrass leaf length was correlated with leaf width (r=0.7842). Due to these correlations, we conducted a multicollinearity study. The PROC REG SAS output shows that all of the variance inflation of the parameters of the environmental variables showed a value less than 5. Hence, the multicollinearity issue was not a factor in the regression analysis.

Significant differences ($P \leq 0.05$) between the habitat types were confirmed using the SAS ANOVA for variables: elevation ($P < 0.001$), slope ($P < 0.001$), topographic moisture ($P = 0.01$), crown cover of the overstory ($P < 0.001$), crown cover of the understory ($P < 0.001$), the successional stage ($P < 0.001$), and depth of the litter layer ($P = 0.03$). There were no significant differences between the aspect of the habitat types nor the percent cover of beargrass between locations.

A Duncan multiple range post-hoc procedure determined which habitat types differed for these variables (Table 2) and showed that the high locations were significantly different from both the western and eastern low elevation sites for variables elevation and slope (α=0.05). The litter layer depth, percent overstory cover and successional stage were significantly lower in the western low elevation sites than in the high elevation and eastern low elevation sites while the understory cover was significantly higher in the eastern low elevation sites than the other habitat types (α=0.05).

Results from a regression analysis of the effects of environmental variables on beargrass morphology found that beargrass percent cover is significantly affected by elevation (P-value <0.0001), slope (P-value<0.0001), canopy cover of the overstory (P-value =0.0005), topographic moisture (P-value = 0.0067), successional stage (P-value =0.0005) and the understory cover (P-value = 0.0001).

TABLE 2. Environmental attributes of the three habitat types surveyed in the ONF.

	Eastern Low Elevation	High Elevation	Western Low Elevation
Total number of sites sampled	22	20	3
Number of original plots relocated	19	9	0 (all logged)
Mean Elevation (m)	216.68 (b)	834.48 (a)	109.73 (b)
Mean Aspect (°)	199.55 (a)	181.05 (a)	203.67 (a)
Mean Slope (%)	4.05 (b)	46.95 (a)	1.00 (b)
Mean Topographic Moisture (1-9)	4.97 (mesic) (a)	4.08 (dry mesic) (a)	4.83 (mesic) (a)
Mean Overstory (%)	72.86 (a)	67.85 (a)	6.67 (b)
Mean Understory (%)	89.41 (a)	59.05 (b)	38.83 (b)
Mean Successional Stage (1-9)	5.55 mature forest (a)	5.95 mature forest (a)	1.33 new clearcut (b)
Mean Litter Layer Depth (cm)	8.69 (a)	10.67 (a)	2.24 (b)
Most Common Plant Associations	TSHE/GASH-MANE TSHE/GASH-XETE	ABAM/XETE TSHE/GASH-MANE TSME/VAAL-ERMO	TSHE/PYFU/ GASH-XETE TSHE/VAAL-GASH
Most Common Vegetative Zone	TSHE	ABAM	TSHE
Most Common Regolith	Continental glacial and glacial fluvial	Neutral Colluvium	Continental glacial
Most Common Bedrock	Mixed	Basalt	Sandstone
Most Common Soil Texture	Silt	Silt and Rock	Organic Matter (Logs)

Means marked with different letters are significantly different as informed by a Duncan multiple range test post-hoc procedure for ANOVA.

ABAM = Silver fir (*Abies amabalis*), MANE = Oregon grape (*Mahonia nervosa*), GASH = salal (*Gaultheria shallon*), ERMO = Avalanche lily (*Erythronium montanum*), PYFU = western crabapple (*Pyrus fusca*)TSHE= western hemlock (*Tsuga heterophylla*), TSME = (*Tsuga mertensiana*), VAAL = Alaska huckleberry (*Vaccinium alaskaense*), XETE= beargrass (*Xerophyllum tenax*)

Changes in Beargrass Percent Cover, Canopy Cover of Overstory and Understory, and Successional Stage

For the 11 plots originally sampled in 1986, the paired samples t-tests performed between current and past conditions found a significant decrease (α=0.05) between the historic and current percent cover of beargrass (P = 0.04). In 1986 the plots had an average of 2% beargrass whereas in 2003, the same plots had 1% beargrass. Canopy cover of the overstory significantly increased (P = 0.04) in that time from 74% to 80%, and the understory significantly increased (P = 0.04) from 96% to 99% cover. While trends suggested an increase in successional stage from 5.45 to 6.09, this change was not significant. Significant differences were not found between current conditions in the plots and those recorded in 1993 and 1998 (Table 3).

Discussion

The beargrass sites surveyed at the ONF fell into three distinct groups (Figure 4). Group I was characterized by plots established at high elevations (greater than 375 m), had steep slopes (average of 47%), the majority within the Pacific Silver Fir Zone, and had bedrock comprised primarily by basalt (Table 2). Group II was comprised (with one exception) of sites on the eastern lowlands of the Olympic Peninsula, with an average elevation of 217 m, an average slope of 4%, and most plots in the Western Hemlock Zone (Table 2). Group III separated due to differences in successional stage and canopy cover. All Group III sites have been altered through logging activity conducted within 20 years of this study. Group III contains all of the western low elevation bogs surveyed in this study and three eastern low elevation sites that had been logged. Three western Peninsula sites have been returned to the Quinault Tribe and are no longer part of the ONF. They were logged in 1988 and it was impossible to relocate original plot centers. The three eastern low elevation sites that fit better with the three western low elevation sites were also logged as part of a savanna restoration project (Peter and Shebitz 2006) and

TABLE 3. Results of Paired Samples t-Test between Historic and Current Conditions.

	Paired Differences								
					95% CI				
	Pair	Mean	Std. Dev.	SE Mean	Lower	Upper	T	Df	Sig.
1986 v. 2003	XETE	0.83	1.19	0.36	0.03	1.63	2.30	10	**0.04**
	CCover	-5.46	7.57	2.28	-10.54	-0.37	-2.39	10	**0.04**
	CCunder	1.91	2.77	0.84	0.05	3.77	2.28	10	**0.04**
	Succ	-0.64	0.67	0.20	-1.09	-0.18	-3.13	10	**0.01**
1993 v. 2003	XETE	-0.91	3.62	1.09	-3.34	1.52	-0.84	10	0.42
	CCover	-0.46	10.32	3.11	-7.39	6.48	-0.15	10	0.89
	CCunder	3.55	7.90	2.38	-1.77	8.86	1.49	10	0.17
	Succ[a]	-	-	-	-	-	-	-	-
1998 v. 2003	XETE	0.81	2.06	0.84	-1.35	2.97	0.96	5	0.38
	CCover	14.47	25.97	10.60	-13.08	41.42	1.34	5	0.24
	CCunder	2.50	13.87	5.61	-12.05	17.05	0.44	5	0.68
	Succ	0.50	1.76	0.72	-1.35	2.35	0.70	5	0.52

95% CI = Confidence interval of the difference, XETE= percent cover of beargrass, CCover= percent canopy cover of the overstory, CCunder= percent cover of the understory, Succ = successional stage (1-9). Significant ($\alpha = 0.05$) values are in **bold**. The standard error of the difference for successional stage between 1993 and 2003 is 0.

their distribution in Figure 3 is most influenced by their open canopy cover.

With our knowledge of each site location and the environmental data collected, we classified three of our sites as western low elevation, 22 as eastern low elevation, and 20 as high elevation. The sample size for the western low elevation sites is appreciably lower than those of the eastern low elevation and high elevation sites. The high variability that is likely to characterize the western sites may make it challenging to identity true differences between the three habitat types. Despite the difference in sample sizes, we did find distinctions between the habitat types that are discussed below.

Occurrence of Beargrass in Low-elevation Sites

We believe that the distribution of beargrass in low elevation sites may have arisen as a result of the glacial history and subsequent environmental and cultural history of the Olympic Peninsula. Both the pollen and plant macrofossil records from this region suggest that conditions were cold and dry during alpine glaciation, resulting in a forest mosaic of temperate and subalpine species in the lowland after 12,500 ybp (Barnosky 1983). The open canopied, cold and dry conditions of this time made it possible for beargrass to colonize low elevation sites.

By the mid-Holocene (6,000-4,500 ybp) summer insolation was less than it was during the early Holocene and the effects of drought and monsoonal precipitation were reduced in strength (Brubaker 1991, Whitlock and Knox 2002). It is likely that at this time beargrass prairies and savannas began to shrink in size due to forest expansion, a trend that would continue throughout the rest of the Holocene.

The development of mesophytic forest, including Douglas-fir and cedar forests, in the late Holocene is related to these changes in climate as it became more like current conditions (Barnosky 1983, Dunwiddie 1983, Long et al. 1998). Forests generally became closed during this period (Whitlock and Knox 2002), leading to beargrass beginning to colonize the subalpine zones of the Cascades, Olympics, Sierras and Rocky Mountain Ranges. Yet some beargrass remained at the low elevations on the Olympic Peninsula, primarily in areas characterized by soil derived from Vashon recessional continental glacial drift (Jones 1936, Barnosky 1983). It is beyond the scope of this study, however, to determine if the soils contributed to the persistence of beargrass.

Many of the low elevation prairies and savannas persisted into the 1850s, despite sufficient precipitation to support the growth of forests. Humans arrived in the PNW over 10,000 ybp and there is evidence of habitation near prairies on the

Olympic Peninsula that dates back to about 3,500 ybp (Wray and Anderson 2003, Peter and Shebitz 2006). It is possible that beargrass persisted in the area by virtue of anthropogenic maintenance of its habitat through burning. Wray and Anderson (2003) hypothesize that Native Americans began burning prairies during the cooling trend 3,000 to 4,000 ybp.

Ecological and Cultural Descriptions of the Habitat Types

Western low elevation habitat type

Each of the western low elevation beargrass sites sampled for this study occurred within the Western Hemlock Zone. This zone is characterized as warm temperate to maritime and has soils with a well developed O horizon (Henderson et al. 1989). The mean annual precipitation for the sites in this habitat type is 305 cm (Henderson et al. 1989) and elevation of the sites ranged from 110 m to 115 m above sea level.

The three sites sampled are part of the *Kalmia microphylla* ssp. *occidentalis-Ledum groenlandicum/ Xerophyllum tenax/ Sphagnum* spp wetland habitat (Kunze 1994, Kulzer et al. 2001), a dry sphagnum bog that occurs in the southwest of the northern Puget Trough lowlands, including in western Jefferson and Clallam counties. These bogs dry in the summer and there are often signs of past fire, which might be an important factor in their formation and maintenance (Kulzer et al. 2001). Shrubs form a relatively open canopy, which enables beargrass to receive adequate sun exposure to promote flowering. In these shallow peatland systems, beargrass dominates the drier portions (Kulzer et al. 2001). The small number of study sites of this habitat type is due to the scarcity with which the habitat occurs on the western Olympic Peninsula and the limited distribution of beargrass in the region. It is possible that the few sites where beargrass does occur may be limited to those areas that were anthropogenically managed in the past.

One of the three plots in the western low elevation habitat types had the presence of camas (*Camassia quamash* var. *azurea*), an important root crop of western Washington Native Americans (Storm and Shebitz 2006). Justine E. James, Jr., a Quinault Indian Nation cultural resource specialist believes that this location was part of the Quinault annual migration route (James, Quinault Indian Nation 2003, personal communication) and it was likely burned after harvesting crops (Shebitz 2005). The Quinault historically practiced small-scale agriculture and used controlled burns to modify the environment for specific plants such as bracken fern and huckleberry, which grow with beargrass in the bogs at each of the three sampled areas in the western Peninsula (James and Chubby 2002).

Eastern low elevation habitat type

All sites in the eastern low elevation habitat type occurred on the southeastern Olympic Peninsula and ranged in elevation from 165 m to 306 m above sea level. The mean annual precipitation for sites in this habitat type is between 200 and 250 cm (Henderson et al. 1989). Three of the sites sampled in this habitat type were located in the Douglas-fir Zone, which is characterized by a dry temperate climate with summer drought. Soils have a thin O horizon and an A horizon low in organic matter and nitrogen (Henderson et al. 1989). The remaining 19 sites sampled in the eastern low elevation habitat type were in the Western Hemlock Zone, yet were dominated by Douglas-fir.

Prior to European settlement, the southeastern Olympic Peninsula was likely characterized by a mosaic of prairies, savannas, and woodlands in a forest matrix that was maintained by native peoples for the provision of culturally important plants and animals through repeated burning (Jones 1936, Norton 1979, Boyd 1999 , Lewis and Ferguson 1999, Peter and Shebitz 2006). It is likely that beargrass was a dominant component of the savannas in this system because the area was maintained with an open canopy and limited shrub cover by frequent anthropogenic burning (Jones 1936; Peter and Shebitz 2006).

The suppression of natural and anthropogenic fires throughout the past 150 years has likely resulted in the degradation of beargrass savannas in the region through the encroachment of woody vegetation. Currently, beargrass in the eastern low elevations of the Olympic Peninsula is found growing under gaps in the forest canopy and at the edges of roads bordering forests where it receives partial shade.

High elevation habitat type

High elevation habitat type sites ranged from 375 m to 1069 m above sea level. The mean annual precipitation in the high elevation beargrass sites surveyed is 250 cm (Henderson et al. 1989). Dominant overstory trees included Douglas-fir, western hemlock, and mountain hemlock.

Nine of the high elevation sites occurred in the Silver Fir Zone, eight in the Western Hemlock Zone, and three in the Mountain Hemlock Zone. The Silver Fir Zone occupies the middle elevations up to about 915 m in elevation. At lower elevations, it is usually replaced by the Western Hemlock Zone, and at higher elevations by the Mountain Hemlock Zone. The Silver Fir Zone has a cool climate with moist soils with a well developed O horizon (Henderson et al. 1989). When present, the A horizon is high in organic matter. The Mountain Hemlock Zone is generally above 1000 m and is characterized by slow plant growth due to the depth and duration of snowpack. The climate is cold temperate and the soils are moist with a well developed O horizon and when the A horizon is present it is generally high in organic matter and nitrogen. The soils are the most acidic (pH 4.2) of the zones encountered in this study (Henderson et al. 1989). In general, beargrass in the high elevation sites was found under a relatively open canopy (68% average), a limited understory (59% average) and a steep slope (47% slope average) (Table 2).

Changes in Beargrass Cover

On average, a decline in beargrass cover from 2% to 1% was found in plots that were initially measured 17 years prior to being resampled for our study. Three of these plots no longer had any beargrass although in 1986 they were known to have an average of 2% beargrass cover. The 11 sites surveyed in 1986 were all located in the southeastern Olympic Peninsula and were of the eastern low elevation habitat type. Therefore, it is possible that only beargrass in the southeastern Peninsula area is declining. The five-year comparison plots, however, did not have a significant decrease in beargrass cover, despite the fact that all of these plots were on the southeastern Peninsula lowlands. This finding is likely due to the fact that too little time has passed since the original sampling to have significantly influenced the cover of beargrass. In addition, a slight increase in beargrass cover was found for the 10-year comparison plots. All but two of the 11 plots revisited after 10 years were in the high elevations. Therefore, it seems that beargrass populations sampled in this high elevation habitat type are not threatened. It is also possible that, despite cross-training between the two teams, variation in sampling accounted for some differences in each of the habitat types. Whether changes in cover of beargrass have ecological significance is beyond the scope of this study.

The 6% increase in tree canopy cover over the past 17 years in those sites with a decline in beargrass suggests that one cause of a change in beargrass cover is succession resulting from the suppression of anthropogenic and natural fires. The forests on the southeastern Olympic Peninsula were likely of a moderate/mixed severity fire regime with 25- to 75-year fire-return intervals (Agee 2002, Peter and Shebitz 2006). In some areas of the southeastern Peninsula, the Skokomish historically burned as often as every 2-3 years to maintain prairies and savannas (Peter and Shebitz 2006).

Throughout the past century, fire suppression policies and a decline in anthropogenic burning have led to the encroachment of what remained of most prairies and savannas in the Pacific Northwest (Clark and Wilson 2001, Lepofsky et al. 2003). Rapid forest succession on former beargrass-dominated savannas on the southeastern Olympic Peninsula after 1877 demonstrates forest potential in the absence of fire and the essential role of anthropogenic burning in maintaining open-canopied habitat suitable for beargrass growth (Peter and Shebitz, 2006).

Another factor that all 17-year comparison sites had in common is that they were within 800 m from USDA Forest Service roads accessible with a passenger car. This may also be contributing to the decline in beargrass cover. Beargrass, traditionally gathered as a basketry plant by local tribes, is coming under extreme harvest pressure from non-native gatherers who sell the leaf blades to florists. Since the 1980s, there has been a rise in the gathering of non-timber forest products such as beargrass by the floral industry (Hansis 1998). The high demand for beargrass in the international market creates an influx of non-traditional harvesters concerned with bulk collection rather than selecting only the "best" material as many tribal basketmakers try to do (Kramer 2001, James 2002). Quinault and Skokomish tribal members have expressed concern that the floral industry is practicing unsustainable harvesting by taking the entire plant (Shebitz 2005). While conducting research for this study, we commonly saw trucks carrying loads of beargrass and salal. On USDA Forest Service roads closest to 10 of the 11 sites that were used in the 17 year comparison, we saw beargrass being trucked out of the area, despite the fact that the ONF did not give beargrass harvesting permits to nontribal members (Patricia Grover, Olympic National Forest, personal communication 2005). Local tribes have witnessed an increase in this activity in the last 20-25 years (Shebitz 2005).

In addition to being under harvesting pressure, much beargrass habitat on the western Peninsula has been logged. The logging activity was evident in this study at the three sites on the western Olympic Peninsula lowlands that were clear-cut since originally sampled. While the open canopy created through logging could potentially benefit beargrass, studies conducted with high-elevation beargrass in the Cascades of Oregon and Washington show a decrease in beargrass cover following clear-cut logging (Dyrness 1973, Halpern and Spies 1995), perhaps due to soil compaction and immediate competition with shrubs following the disturbance (Crane 1990).

Conclusion

In the ONF, beargrass' occurrence in three distinct habitat types appears to be the result of both the natural and cultural history of the region. Although it is primarily known as a subalpine species, the Olympic Peninsula offers a glacial history and subsequent environmental and cultural history that have apparently created suitable conditions for beargrass to inhabit low elevations on both the dry, eastern side of the Olympic Peninsula, and the wetter west side. Many of the forests at the lower elevations in which beargrass grows, such as on the southeastern Olympic Peninsula, were likely maintained as prairies or savannas through indigenous burning, but have succeeded into forests due to changes in Native American's burning regimes and a policy of fire suppression over the past century.

Beargrass, like many species, has a distribution that is changing due to land use practices and human use. Understanding the direction and implications of those changes is critical to conservation planning. We believe that both an increase in canopy cover because of changing landscape management practices and the reported increase in commercial harvesting of the species are having a negative influence on its abundance in the low elevations of the Olympic Peninsula. Therefore, an understanding of the role of current fire suppression and harvesting impacts on beargrass' current population status are critical in forming the foundation for the conservation of this culturally significant species on the low elevations of the Olympic Peninsula.

Acknowledgements

Funding for this research was provided by the University of Washington, College of Forest Resources, the ARCS Foundation, and the Washington Native Plant Society, Puget Sound Chapter. We gratefully acknowledge the support and cooperation of Jan Henderson, Robin Lesher, and David Peter of the Olympic National Forest who provided the baseline data for this paper, and trained us on their field techniques. We thank the Skokomish and Quinault tribal members who generously shared their knowledge of beargrass and its habitat with us and greatly appreciate field assistance provided by Justine E. James, Jr. from the Quinault Indian Nation and Sergio Capozzi of EDAW, Inc. This manuscript was completed with an Untenured Faculty Research Initiative Grant from Kean University's Office of Research and Sponsored Programs. Funding for the publication of this manuscript was generously provided by Kean University's College of Natural, Applied, and Health Sciences, and the Northwest Science Association.

Literature Cited

Agee, J. K. 2002. The fallacy of passive management. Conservation Biology 3:18–25.

Barnosky, C. 1983. Late-quarternary vegetational and climatic history of southwestern Washington. Ph.D. Dissertation, University of Washington, Seattle, Washington.

Blatner, K. A., and W. E. Schlosser. 1997. The floral and Christmas greens industry of the Pacific Northwest. Project to the USDA Forest Service Pacific Northwest Research Station, Portland, Oregon.

Boyd, R. 1999. Introduction. Pages 1-30 *In* R. Boyd (editor), Indians, Fire, and the Land in the Pacific Northwest. Oregon State University Press, Corvallis, Oregon.

Brubaker, L. B. 1991. Climate change and the origin of old-growth Douglas-fir forests in the Puget Sound lowland. Pages 17-24 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, tech. coords. Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report, PNW-GTR-285. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Clark, D. L., and M.V. Wilson. 2001. Fire, mowing, and hand-removal of woody species in restoring a native wetland prairie in the Willamette Valley of Oregon. Wetlands 21:135-144.

Cooke, S. S. 1997. A Field Guide to the Common Wetland Plants of Western Washington and Northwestern Oregon. Seattle Audubon Society, Seattle, Washington.

Crane, M. F. 1990. *Xerophyllum tenax*. *In*: Fire Effects Information System. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available online at www.fs.fed.us/database/feis/ [2004, May 13].

Dunwiddie, P. W. 1983. Holocene forest dynamics on Mount Rainier, Washington. Ph.D. Dissertation, University of Washington, Seattle, Washington.

Dyrness, C. T. 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology 54:57-69.

Halpern, C. B., and T. A. Spies. 1995. Plant species diversity in natural and managed forest of the Pacific Northwest. Ecological Applications 5:913-934.

Hansis, R. 1998. A political ecology of picking: non-timber forest products in the Pacific Northwest. Human Ecology 26:67-86.

Heinrichs, M. L., R. J. Hebda, and I. R. Walker. 2001. Holocene vegetation and natural disturbance in the Engelmann spruce-subalpine fir biogeoclimatic zone at Mount Kobau, British Columbia. Canadian Journal of Forest Resources 31: 2183-2199.

Henderson, J. A., D. H. Peter, R. D. Lesher, and D. C. Shaw. 1989. Forested Plant Associations of the Olympic National Forest. USDA Forest Service Pacific Northwest Region. R6 ECOL Technical Paper 001-88. Portland, Oregon.

Henderson, J., and R. Lesher. 2003. Survey protocols for benchmark plots (permanent intensive ecoplots) for western Washington DRAFT. USDA Forest Service Pacific Northwest Region, Portland Oregon.

Higgins, S., K. Blatner, B. K. Kerns, and A. Worthington. 2004. Relationship between *Xerophyllum tenax* and canopy density in the southern Cascades of Washington. Western Journal of Applied Forestry 19:82-87.

Hitchcock, C. L. and A. Cronquist. 1973. Flora of the Pacific Northwest: An Illustrated Manual. University of Washington Press, Seattle, Washington.

James, J. E. 2002. Salmon River Watershed Analysis, Cultural Resource Module. Quinault Indian Nation. Tahola, Washington.

James, J. E., and L. A. Chubby. 2002. Quinault. Pages 99-116 *In* J. Wray (editor) Native Peoples of the Olympic Peninsula: Who We Are. University of Oklahoma Press, Norman, Oklahoma.

Jones, G. N. 1936. A Botanical Survey of the Olympic Peninsula, Washington. University of Washington Publications in Biology Vol. 5. University of Washington, Seattle, Washington.

Kramer, B. 2001. Dangerous harvests? Natural resources: Forest Service studying whether popularity of beargrass is harming ecosystem. *The Spokeman-Review.* June 5.

Kruckeberg, A. 2003. Gardening with native plants of the Pacific Northwest. University of Washington Press, Seattle, Washington.

Kulzer, L., S.Luchessa, S. Cooke, R. Errington, and F. Weinmann. 2001. Characteristics of the Low-Elevation Sphagnum-Dominated Peatlands of Western Washington: A Community Profile. EPA Region 10, Seattle, Washington.

Kunze, L. M. 1994. Preliminary Classification of Native, Low Elevation, Freshwater Wetland Vegetation in Western Washington. Washington State Department of Natural Resources, Olympia, Washington.

Lepofsky, D., E. K. Heyerdahl, K. Lertzman, D. Schaepe, and B. Mierendorf. 2003. Historical meadow dynamics in southwest British Columbia: a multidisciplinary analysis. Conservation Ecology 7:5. Available online at www.consecol.org/vol7/iss3/art5.

Lewis, H. T., and T. A Ferguson. 1999. Yards, corridors, and mosaics: how to burn a boreal forest. Pages 164-184 *In* R. Boyd (editor), Indians, fire and the land in the Pacific Northwest. Oregon State University Press, Corvallis, Oregon.

Long, C.J., C. Whitlock, P. J. Bartlein, and S. H. Millspaugh. 1998. A 9,000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study. Canadian Journal of Forest Resources 28:774-787.

Maule, S. M. 1959. *Xerophyllum tenax*, squawgrass, its geographic distribution and its behaviour on Mount Rainier, Washington. Madrono 15:39-48.

McCune, B., and A.J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4.25. Mjm Software Design, Gleneden Beach, Oregon.

Munger, S. H. 2003. Common to This Country: Botanical Discoveries of Lewis and Clark. Artisan Books, New York.

Nordquist, D.L. and G.E. Nordquist. 1983. Twana Twined Basketry. Acoma Books, Ramona, California.

Norton, H. 1979. The association between anthropogenic prairies and important food plants in western Washington. M.S. Thesis. University of Washington, Seattle, Washington.

Peter, D., and D. J. Shebitz. 2006. Historic anthropogenically-maintained beargrass savannas of the southeastern Olympic Peninsula. Restoration Ecology 14:605-615,

Pendergrass, K. L., P. M. Miller, J. B. Kauffman, and T.N. Kaye. 1999. The role of prescribed burning in maintenance of an endangered plant species, *Lomatium bradshawii*. Ecological Applications. 9:1420-1429.

Pojar, J., and A. MacKinnon. 1994. Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia and Alaska. B.C. Ministry of Forests and Lone Pine Publishing, Vancouver, British Columbia.

Rentz, E. 2003. Effects of fire on plant anatomical structure in native Californian basketry materials. M.S. Thesis. San Francisco State University, San Francisco, California.

Rudall, P. J., K. L. Stobart, W. P. Hong, J. G. Conran, C. A. Furness, C. G. Kite, and M. W. Chase. 2000. Consider the lilies: systematics of liliales. Pages 347-357 *In* K.L. Wilson and D.A. Morrison (editors), Monocots: Systematics and Evolutuion. C.S.I.R.O., Collingwood, Victoria, Australia.

SAS Institute. 2003. SAS 9.1 Statistical Package. SAS Institute, Inc. Cary, North Carolina.

Shebitz, D.J. 2005. Weaving traditional ecological knowledge into the restoration of basketry plants. Journal of Ecological Anthropology 9:51-68.

SigmaPlot. 1992. Scientific Graph System. Jandel Corporation, Chicago, Illinois.

Stewart, C. 1994. Wildflowers of the Olympics and Cascades. Nature Education Enterprises, Port Angeles, Washington.

Storm, L. and D. Shebitz. 2006. Evaluating the purpose, extent, and ecological restoration applications of indigenous burning practices in Southwestern Washington. *Ecological Restoration* 24: 256-268.

Thomas, M. G. and D. R. Schumann. 1993. Income opportunities in special forest products: self-help suggestions for rural entrepreneurs. USDA Forest Service Agriculture Information Bulletin AIB-666. State and Private Forestry, Washington, DC.

Vance, N. C., P. Bernhardt, and R. M. Edens. 2004. Pollination and seed production in *Xerophyllum tenax* (Melanthiaceae) in the Cascade Range of central Oregon. American Journal of Botany 91:2060-2068.

Whitlock, C., and M. A. Knox. 2002. Prehistoric burning in the Pacific Northwest: human versus climatic influences. Pages 195-132 *In* T. Vale (editor) Fire, Native Peoples, and the Natural Landscape. Island Press, Washington, D.C.

Wood, R.L. 1976. Men, Mules and Mountains: Lieutenant O'Neil's Olympic Expeditions. The Mountaineers, Seattle, Washington.

Wray, J., and M. K. Anderson. 2003. Restoring Indian-set fires to prairie ecosystems on the Olympic Peninsula. Ecological Restoration 21:296-301.

Received 31 January 2007
Accepted for publication 22 February 2008