Low Elevation Beargrass on the Olympic Peninsula: Effects of Light Levels and Stand History on Reproduction and Leaf Morphology Related to Cultural Uses

By
Mark Thompson

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Table of Contents

List of Figures

List of Tables

Appendix

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ABSTRACT

Beargrass (*Xerophyllum tenax* (Pursh) Nutt.) is a plant of cultural significance to Native Americans for use as a basketry fiber as well as an economically important non-timber forest product used in the floral greens industry. Former low elevation beargrass-dominated savanna and prairie complexes on the southeastern Olympic Peninsula that were maintained through indigenous burning have been lost due to nearly 150 years of fire suppression and subsequent forest succession. Tribal harvesters have expressed concern that the combination of forest encroachment and careless techniques and overharvest by the floral greens industry has led to a decline in the quality and quantity of beargrass suitable for weaving. Previous research documenting a decline in beargrass cover on the southeast Olympic Peninsula over the past 25 years has supported this belief.

A prescribed burn was implemented to a portion of a historical savanna in the Olympic National Forest in 2003 to restore the community of shade-intolerant prairie species. This project examines the effects of photosynthetically active radiation (PAR) levels on beargrass morphological characteristics such as leaf length, width, and coloration that are important to weavers, as well as on sexual and vegetative reproduction on plots established in the restoration unit and on two forested units of differing stand characteristics. Significant differences were found between treatment units for leaf length, with the longest leaves found in the forested units, and for flowering, with greater instances of sexual reproduction in the restoration unit. Leaves within the restoration unit showed the lesser pigmentation favored by weavers. The only statistically significant association with PAR was for vegetative reproduction via offshoots from

the rhizome, which showed a positive correlation with increasing PAR. There was not a significant difference in leaf width between treatment units. Results suggest that other factors, such as soil temperature, reduced competition from evergreen shrubs, and exposure to post-burn nutrients may play a more important role in desired morphological characteristics than PAR level alone and that the restored area may not have had enough time to develop the partially shaded conditions that result in the best properties for weaving.

KEYWORDS

Beargrass, Photosynthetically Active Radiation, leaf morphology, reproduction, anthropogenic burning, savanna restoration, cultural uses in basketry

INTRODUCTION

Prairies and savannas in western Oregon and Washington are a vanishing ecosystem with unique assemblages of species, many of which are endangered. Prairies typically support a greater diversity of species than the surrounding coniferous forests. With the arrival of the first European settlers in the 1800s in a thickly forested landscape, prairies were frequently the first systems to be homesteaded and farmed, as they were already cleared of trees and could be converted for livestock use. As development ensued, and with the cessation of indigenous burning practices and subsequent coniferous forest encroachment, the current extent of prairies, oak savannas and woodlands has shrunk to less than 5% of their historical range prior to Euro-American settlement.

Prairie ecosystems have long been an interest of mine, having grown up in the Willamette Valley in Oregon and volunteering with organizations dedicated to the preservation of oak savannas. I have been involved with seed collection of native wet prairie and savanna species to be broadcast following prescribed burning of remnant prairies in the Tualatin Valley, conducting germination trials of the state-listed endangered species *Delphinium leucophaeum* in Oregon, and with monitoring populations of rare or threatened species in the Wenatchee Mountains and shrub-steppe of eastern Washington, so I was interested in a project involving native plant restoration.

When I contacted Dave Peter with the Olympic National Forest, it was initially for his work studying oak habitats at Fort Lewis. In speaking with him, I learned of a type of prairie ecosystem I had not been aware of: that of the low-elevation beargrass savanna. Whereas most prairies in western Washington consist of *Festuca roemeri* (Pavlick) E. B. Alexeev) (Roemer's fescue) and *Camassia quamash* (Pursh) (common camas) as their dominant species, in these beargrass savannas, the two species were notably absent. Furthermore, beargrass savanna complexes disappeared completely in the twentieth century with the cessation of the anthropogenic burning of these prairies by Native Americans, which was necessary to prevent the closure of the forest canopy. Both the limited extent of these historic prairies and the relative lack of research into their ecological processes made the project very attractive to me.

In 2003, the Olympic National Forest carried out what was to be the first of a series of prescribed burns on a 30-acre section of the historic beargrass savanna complex north of the South Fork of the Skokomish River near Dennie Ahl seed orchard. Due to budgetary constraints, the proposed 2-3 year burning cycle has not been realized. The prospect of examining the post-fire effects of such a unique and culturally significant landscape was a great opportunity to study the naturally regenerating shade-intolerant species that had long been absent from the site prior to the burn. While the project was part of a larger demographic study by the Olympic National Forest, I chose to focus on the effects a closed-canopy vs. an open canopy had on beargrass reproduction and how the release from overstory competition was impacting production of leaves suitable for traditional uses as an important basketry fiber.

BACKGROUND

Beargrass

Figure 1. Beargrass inflorescence on the Olympic Peninsula.

Beargrass (*Xerophyllum tenax* (Pursh) Nutt.) is an evergreen perennial in the Melanthiaceae family with a range from the Sierra Nevada in California, through the Cascades to Stampede Pass in Washington State, the Olympics, and the northern Rockies in Wyoming, Montana, Idaho, southeastern British Columbia and southwestern Alberta (Crane 1990). It is primarily found in montane habitats, although it is found near sea level on the Olympic Peninsula and in the Coast Range of northern California. Given the gaps in its distribution and its range of habitats, it is likely that beargrass may consist of several races (Maule 1959).

Figure 2. Beargrass tussock in the Old Growth unit.

Plants have thick, wiry, strongly scabrous, basal leaves that form large tussocks arising from a 1-2 cm thick woody rhizome with cord-like roots (Hitchcock and Cronquist 1973, Maule 1959). The leaves are keeled upward at the midrib and range from 50-100 cm long and 5-10 mm wide at the base (Maule 1959) and rough-edged from fine serrations on the margins (Vance et al. 2001). Individual leaves are thought to live for at least three years (Rentz 2003) and tussocks are considered to be long-lived because of their continuous production of new offshoots (Crane 1990, Vance et al 2004).

Plants may reproduce sexually or vegetatively through formation of offshoots, or new basal rosettes, from the rhizome (Crane 1990). Flowering has been reported as occurring in 5 to 7 year cycles in some populations (Crane 1990, Vance et al. 2001), while in others it may bloom annually but sporadically (Maule 1959). The inflorescence stalks range from 30-150 cm, producing a dense, club-shaped raceme of white to cream-colored flowers which open successively from bottom to top on slender pedicels 2-5 cm long (Maule 1959, Hitchcock and Cronquist 1973, Vance et al. 2004). Depending on the site, flowering may occur from May to September (Maule 1959). During this season at the study site, the flowering appeared to have occurred from May to early June, as floral inflorescences were expanding during reconnaissance in late April and senescent stalks were present when measurements began in late June.

The flowers are nectarless and self-incompatible, with the stigma recognizing and rejecting pollen from the same plant (Vance et al. 2004). In high elevation populations at least, the most common pollinators are the hover flies (Syrphidae) and flower-visiting beetles (Coleoptera), guilds of pollinators that consume pollen as the primary reward (Vance et al. 2004). In such montane sites, where conditions are cooler and more moist, bees are less common and active, however the floral presentation characteristics of a dense, brush-like appearance from the overlapping perianths and the largely musty-acrid scent with sweet undertones are more representative of fly-pollinated syndromes or the mass-flowering "brush mode" of pollination typical of beetles (Vance et al 2004). Seeds are 4 mm long and enclosed in small, three-lobed capsules, with an average of seven seeds per capsule (Crane 1990, Vance et al. 2004). After seed formation, the individual center dies but may be replaced by new offsets (Hitchcock and Cronquist 1973).

Most of the published literature to date has related to beargrass growing in montane habitats (Maule 1959, Higgins et al. 2004, Vance et al. 2004, Hummel and Lake 2015), only in the last 10 years focusing on the low elevation habitats of the southeastern Olympic Peninsula, a habitat that is likely unique and which has shown signs that total beargrass cover may have declined from 2 percent to 1 percent in the last 29 years since initial sampling in 1986. Shebitz et al. (2008) found that some plots that had originally reported having beargrass coverage of 2 percent in 1986 had no extant beargrass when resampled in 2003.

Native Americans

The Skokomish people are the descendants of the Twana, who occupied the territory along the shore of Hood Canal from roughly the Quilcene River to the mouth of the Skokomish and along the upper canal on the Kitsap Peninsula. The territory extended inland to the uplands and subalpine areas on the eastern flank of the Olympic Mountains (Olympic Peninsula Intertribal Cultural Advisory Committee 2002). Elmendorf (1960) put the number of historical winter villages at nine, with common language but slight cultural variations between each. The winter village functioned as both an economic and social unit, consisting of wood-frame or plank houses. In the summer, bands of villagers dispersed and engaged in food-gathering activities over a broad area, with surpluses stored for winter use. Subsistence activities were thus at a minimum during the winter when religious and ceremonial activities took precedence (Elmendorf 1960). The Skokomish Twana or "people of the river" occupied villages in the valleys of the North and South Forks of the Skokomish River, as well as its main stem, near resource-rich areas. Those that occupied territory near the study site were the Vance Creek Twana, who were wholly inland and whose main village was located in a prairie on the north side of the creek about 3 miles of its drainage into the South Fork of the Skokomish (Elmendorf 1960). Land game, rather than seals or molluscs played a much greater role in the economy of this inland band relative to the saltwater communities (Elmendorf 1960). The chief game animals included elk, black bear, deer, mountain beaver, beaver and muskrat, while vegetable products gathered included various fern roots, camas (*Camassia quamash*), tiger lily (*Lilium columbiana*), huckleberry (*Vaccinium parvifolium* and *Vaccinium ovatum*), blueberry

(*Vaccinium ovalifolium)* and trailing blackberry (*Rubus ursinus*) (Elmendorf 1960, Peter and Shebitz 2006).

The Treaty of Point No Point in 1855 established the reservation at the mouth of the Skokomish and tribal members from other parts of the Twana territory were relocated there along with the Chemakum people, who lived at the northeastern corner of the Olympic Peninsula and whose numbers were much reduced by that time. Among the specifications laid out in the treaty was the provision that the tribe has the right to fish in accustomed waters and to hunt and gather roots and berries on "open and unclaimed lands." These, however, were not rights granted to them by the treaties but rights they had for thousands of years, and by signing the treaties the tribe agreed to share their resources with the settlers in the newly established Washington Territory (OPICAC 2002). Movement to the Skokomish reservation resulted in cultural changes including cessation of many traditional land management practices including the burning to maintain open spaces (Peter and Shebitz 2006).

Anthropogenic Burning

Shebitz et al. (2008) posit that low-elevation beargrass may have arisen during the period following the most recent glaciation about 12,500 ybp, when conditions were cold, dry and open-canopied. By 6000-4500 ybp, the climate shifted to one of less summer insolation and a weakening of the periods of drought and monsoonal precipitation, becoming more like the present and favoring forest expansion and a reduction of beargrass prairies and savannas. Some low-elevation beargrass persisted, however, chiefly in areas characterized by well-drained, nutrient-poor soils derived from Vashon recessional continental glacial drift (Shebitz et al. 2008).

It is hypothesized that Native Americans on the Olympic Peninsula may have begun burning prairies during the cooling trend 3000-4000 ybp (Wray and Anderson, 2003) to maintain open habitat to provide winter range for blacktail deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*), hunt game, and to gather the plants that were valuable sources of carbohydrates, were medicinal, or provided sources of fibers and were shade intolerant (Peter and Shebitz 2006).

Natural fire return interval in the Western Hemlock zone on the Olympic Peninsula was 234 years and 70-100 years in the drier Douglas-fir zones of the Puget Trough (Henderson et al. 1989), and large, stand-replacing fires affected the Skokomish plateau in 1308, 1508, 1668, and 1701 (Henderson et al. 1989, Peter and Shebitz, 2006). This fire return interval is too infrequent to maintain prairies and savannas in western Washington. It may be that in areas where soil water-holding capacity was low, forest growth was slowed and therefore open areas persisted between fires and throughout its range, beargrass is associated with soils that are deficient in nitrogen and potassium and have low productivity (Peter and Shebitz 2006, Shebitz et al. 2009).

According to Skokomish oral tradition, lowland prairies were burned at 2-3 year intervals in autumn after the first frost (Shebitz 2006, Peter and Shebitz 2006). With the cessation of indigenous burning after the relocation to the Skokomish reservation, and a history of fire suppression following European settlement after the 1870s, forests have encroached on what had been a complex of beargrass savannas (herbaceous vegetation with scattered woody plants and some low trees), woodland (widely spaced forest) and parkland (mosaic of small prairies within a woodland or forested matrix) on the plateaus above the North and South Forks of the Skokomish River and this ecosystem is no longer extant.

Peter and Shebitz (2006) used a variety of methods to support the former extent of this savanna complex, including General Land Office (GLO) survey maps from the 1890s, evidence of open areas in 1929 aerial photographs of the region showing few snags or logs (Figure 3), presence of remnant prairie species, existence of old and widely-spaced Douglas-firs with epicormic branching, evidence of bark charcoal and fire scars, and the lack of mound and pit topography that would be expected in successional forests. Currently the former savanna is covered with a dense, relatively even-aged stand of trees 100-120 years old. This rapid succession of forest on the savanna complex after 1877 illustrates the forest potential in the absence of anthropogenic fire (Peter and Shebitz 2006). Figure 4 shows the site as it appeared in 2014 .

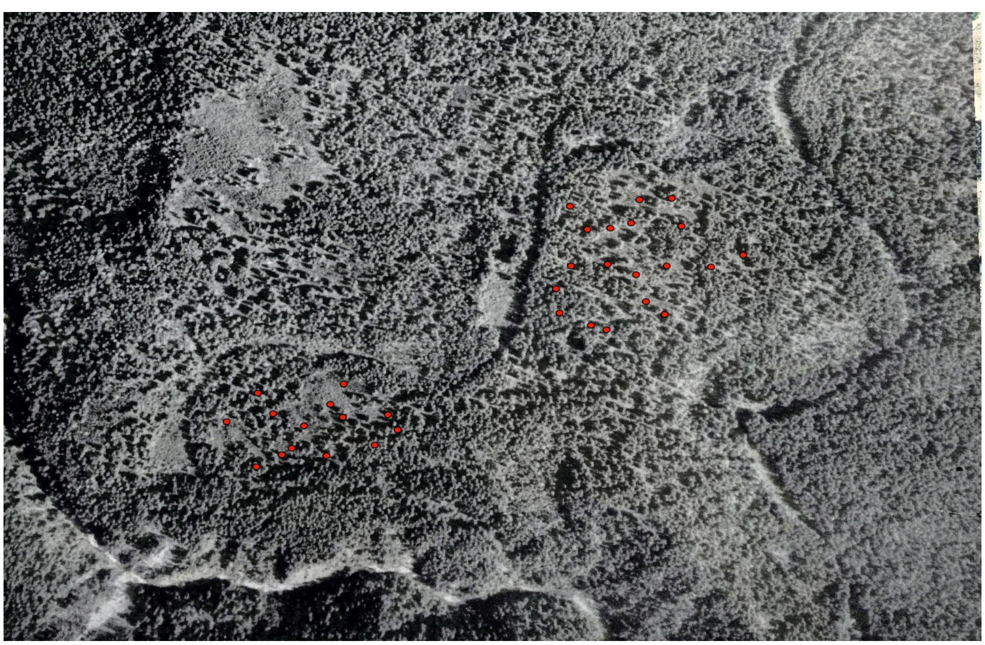

Figure_. Aerial photo of the study site in 1929 showing the existence of canopy gaps, presence of widely spaced large trees and lack of downed wood. Photo courtesy of Olympic National Forest.

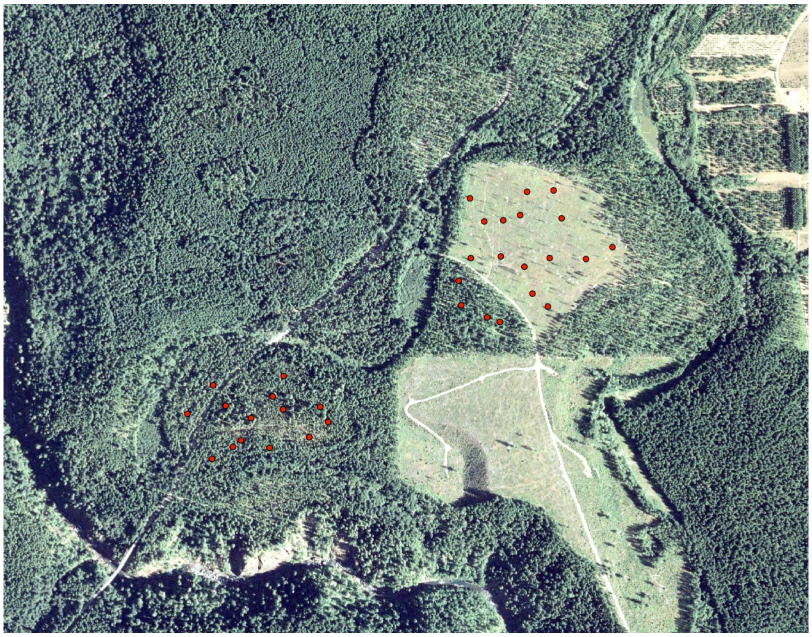

Figure 4. Aerial photo of the site in 2014. Photo courtesy of Olympic National Forest.

Cultural Uses of Beargrass

Beargrass has cultural significance for many Native American tribes in northern California and the Pacific Northwest for its use in basketry, ceremonial regalia and funereal items (Rentz 2003, Shebitz 2005, Hummel et al. 2012). The importance to traditional culture ran deeper than mere aesthetics. Through the physical representation in the baskets themselves, the basket makers' knowledge was passed on to younger generations.

> "A basket is a sacred item that stores many of the belongings of the native people and gives them an avenue to record the history of their people…Our written language may not be in words, on paper or in books, but they are the symbols embroidered and applied to baskets." ~Michael Pavel (Shebitz 2005)

In late July, the time of greatest growth and before the plant entered a senescent state, Twana would travel to the Olympic foothills to collect *xalalshid* (beargrass) (Nordquist and Nordquist 1983). The preferred materials grew in semi-shade where the leaves were long but not brittle (Nordquist and Nordquist 1983). Interviews with tribal basket weavers indicated that the most useful leaves should be at least 2 feet long (61 cm) (Shebitz 2006, Jones 1977). Information is scarce and often conflicting as to optimal width of leaves. They sought strands that were wide enough for weaving (Thompson and Marr 2012), though generally thinner leaves were more desirable for finer basket work, as these could be woven more tightly between a smaller warp (Rentz 2003). None of the master weavers interviewed by Shebitz specified an exact width (personal communication, 2015) and Justine James, Jr. of the Quinault Nation estimated that leaves with a width of 5 mm would be optimal, though weavers often cut them to size based on their needs. He did feel, however, that "there is a standard weavers use to achieve usability, strength of the basket, and incorporation of design into the basket" (personal communication, 2015.) Much of the evaluation was "based on the feel of the fibers, which was a quality sensed by the basket makers but difficult to describe" (Nordquist and Nordquist 1983). It has also been observed that leaves with a higher moisture content may be more valued, as determined by a "squeaky" sound when extracted (Hummel and Lake 2015).

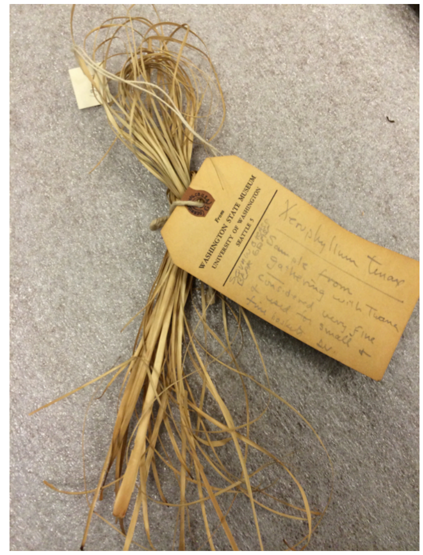

Figure 5. Raw material for basketry. Inscription reads "Sample from gathering with Twana considered very fine and used for small and fine baskets. Accession 1-2169, Burke Museum, University of Washington.

After harvest, leaves were spread out to dry out of direct sun (Nordquist and Nordquist 1983) to bleach to an off-white color that was more accepting of natural dyes, such as yellow from the roots of Oregon grape or black from the blue-grey clay found in wet locations (Thompson and Marr 2012). For this reason, harvesters selected leaves that were less pigmented and had snowy white (Hummel et al. 2012) rather than purplish-red bases (Rentz 2003), which indicated an older, more brittle leaf. Once the leaves had cured, the central rib was removed by making a small notch at the base of the stem and either grasping the stem in the mouth (Nordquist and Nordquist 1983) or using a fingernail or a knife (Hummel et al. 2012) and pulling the leaf away. It was then processed into uniform widths, traditionally using an 8-10” long wooden gauge fitted with two flanges set upright at one end. This end was beveled, allowing the leaf to be pulled downward between the flanges, paring the leaf to a given width (Nordquist and Nordquist, 1983). For large baskets, this would be 1/4-3/8” (6.4-9.5 mm), while for smaller baskets the width would be 3/32-1/8” (2.4-3.2 mm) (Nordquist and Nordquist 1983).

Figure 6. Skokomish larger fine-twined basket depicting the house with mat window motif and a rim design of wolves. Accession 7331 Burke Museum, University of Washington.

While Twana basketry included coiled, twined, plaited and other open weave types, perhaps the most important was the *Tqayas*, or fine-twined overlay basket, which was considered special by the neighboring Puget Sound Salish tribes who primarily made coiled baskets (Thompson and Marr 2012). These were traditionally used as large burden baskets for the collection of molluscs, berries and roots, and were carried on the back, attached by tumplines to a forehead band woven of cattail, cedar bark or wool (Elmendorf 1960). Decorative techniques were beading or imbrication, by which a “piece of contrasting color and texture were inserted and laid down on the foundation, caught in a stitch and folded back with the next stitch catching in the fold. The inserted piece

Figure 7. Basket with beargrass overlay in the dog, human and snake motif. Accession 2-5E1884, Burke Museum, University of Washington.

was then drawn over the second stitch, concealing the sewing" (Thompson and Marr 2012). Beargrass was the most common material used in overlays, which entailed laying extra strands on top of wefts, (Thompson and Marr 1983) and was preferred as a decorative material because of its durability and shiny surface (Thompson and Marr 2012). Main designs on baskets were arranged in horizontal bands, vertical columns, diagonal stripes, or an allover pattern, while rim designs were zoomorphic, representing dogs, wolves, and helldivers, or occasionally geometric representations of the spider web, icicle or mountain (Thompson and Marr 2012). Though many women made baskets for utilitarian uses such as gathering and storing of food, only very talented individuals could be specialists and, as such, devoted most of their time to making highly decorated *tqayas*. Recognition of a weaver's skill and execution of complex or innovative designs earned her extended family prestige and her baskets would be presented as valued gifts at potlatches (Thompson and Marr 2012).

Commercial Uses of Beargrass

Since the 1980s, beargrass has had increasing importance to the floral greens industry as a filler material in floral arrangements along with other non-timber forest resources such as salal (*Gaultheria shallon*), evergreen huckleberry (*Vaccinium ovatum*), and western sword fern

(*Polystichum munitum*). Ninety percent of the greens used by florists in the United States comes from the coastal strip from northern California to Washington (Blatner and Alexander 1998). In 2002, the harvest in Washington alone was worth an estimated $236 million, 80 percent of which was exported to German and Dutch wholesalers (Draffan 2006). While salal accounts for a greater proportion of the revenue, the Washington State Department of Labor & Industries estimates that 10 million pounds of beargrass is exported to Europe each year (Draffan 2006).

Beargrass leaves are valued for their ability to lend structure and a long-lasting background to more colorful and expensive flowers in bouquets (Blatner and Alexander 1998). They may be bleached, dyed and dried for dry floral arrangements and crafts (Higgins et al 2004). Long leaves of up to 72 cm are the most valued and, to meet commercial standards, must be dark green and free of blemishes and brown tips (Schlosser et al. 1992). Generally, the floral greens industry favors plants growing in partial shade, for brighter conditions may produce chlorotic leaves or necrosis and quality is not commercial grade after recent burns or clear cuts (Higgins et al. 2004).

The harvest season is typically late fall and winter when demand in Europe peaks (Vance et al. 2001) but may occur at any time (Hummel et al 2012). Harvesters obtain permits to gather on USDA Forest Service or other public lands or contractors may hire several people to collect beargrass on lands for which they have obtained a lease (Higgins et al. 2004). There is concern that species such as beargrass and salal are being heavily harvested, possibly affecting the quality, growth and reproductive capacity of the product (Vance et al. 2001). There is a long regenerative period of 10 years or more for beargrass plants that have been carelessly ripped from the soil rather than selectively harvesting blades by cutting them above ground (Shebitz, 2006). Tribal members have reported a decline in the number and quality of beargrass plants due to indiscriminate harvesting by the floral industry. They have expressed concern that an influx of outside harvesters concerned with bulk collection has led to the entire plant being taken rather than selecting only the best leaves, as tribal basketmakers do (Shebitz 2006). Despite the permitting process, illegal harvesting or poaching often occurs (Vance et al. 2004), especially on sites that are easily accessible from forest service roads--locations valued by tribal basketmakers, many of whom are now elderly (Shebitz 2006).

While beargrass can be cultivated, it is difficult (Pojar and McKinnon 1994), particularly as it is strongly mycorrhizal and may need appropriate soil to grow (Vance et al 2001). For this reason successful propagation may elude growers, making commercial cultivation an unlikely prospect and necessitating wild harvest which may put pressure on the population if sustainability is not monitored. The unfeasibility of commercial cultivation can also be a destabilizing factor for the floral greenery industry in Mason County and elsewhere in the region under the increased competition from growers in Florida and Central America who can produce floral greens for similar uses, such as leatherleaf fern, cheaply, efficiently and year round without canopy cover under shade netting and with machinery, fertilizer and labor, flooding the market with supply should product quality decline through overharvesting in Washington state (Draffan 2006).

SITE LOCATION

The study site is the Olympic National Forest Boundary Beargrass Savanna Restoration Project, located at the southeast corner of the ONF on the plateau north of the South Fork of the Skokomish River in Mason County, Washington at an elevation of 180-213 meters. It lies within the Western Hemlock (*Tsuga heterophylla*) Zone but is dominated by Douglas-fir (*Pseudotsuga menziesii*) (Henderson et al. 1989, Shebitz et al. 2008). Average annual precipitation is 226 cm (Peter and Shebitz 2006). In 2001, the restoration unit was thinned to the density represented in aerial photographs from 1929 (15 trees/ha) and on September 30, 2003, a 30-acre portion of the former woodland underwent a prescribed burn to begin the process of restoration (Peter and Shebitz 2006). In the 11 years following the burn, there has been some recruitment of *Pseudotsuga menziesii* (Douglas-fir) and an understory primarily dominated by *Pteridium aquilinum* (bracken) (Figure 8). In order to monitor the restoration process in the restoration burn area, a network of plots had been established in and outside of the burn within the area of former woodlands and savannas. The network consists of 26 randomly located plots that are 0.05 ha in size (12.62 m radius) that had been randomly located within each area using a GIS routine and GPS for ground location. Additionally, two 0.08 ha plots (16.06 m radius in the

Figure 8. Site conditions in the Restoration Unit 11 years after the prescribed burn.

restoration unit and three 0.04 ha plots (11.35 m radius) in the woodland that had been installed by the USFS Ecology Program were also used. There are a total of 15 plots in the restoration burn area (Restoration) and 4 in an adjacent area that had been recently lightly thinned but unburned (Thinned). The thinned unit is slightly downslope from the restoration burn unit and is wetter with many red alder (*Alnus rubra* Bong.) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa* Torr. & A. Gray ex Hook). The nearby forested plots are part of the former savanna complex and divided into 8 plots that are on land that had the large woodland dominants removed by railroad loggers in the 1930s (Cut Old Growth) (Figure 9) and 6 plots in an area that did not (Old Growth) (Figure 10). In the Cut Old Growth unit, there are many stumps but few old trees while the reverse is true in the Old Growth unit.

Figure 9. Site conditions in the Cut Old Growth unit, showing in-fill of even-aged stands of primarily *Pseudotsuga menziesii* with a dense undergrowth of *Gaultheria shallon.*

Figure 10. Site conditions in the Old Growth Unit, showing the continued presence of widely spaced older, large diameter trees.

The soils were formed by glacial outwash from the Vashon Ice Sheet. The soil series in the restoration units is the Bogachiel-Ishmael complex characterized by very deep, somewhat excessively well drained soils formed in glacial outwash on glacial terraces on slopes of 1 to 5 percent, while that of the woodland flats is the Duskpoint series (David Peter, personal communication May, 2015), also consisting of very deep, somewhat excessively drained soils, but formed in glacial outwash in glacial valleys. Bogachiel and Ishmael both have O horizons containing slightly decomposed needles, leaves, twigs and other wood fragments, though the Ishmael series extends an inch deeper than Bogachiel, to three inches, and has a wavy boundary, whereas Bogachiel is smooth. The A horizon for Ishmael extends to a depth of 12 inches and is composed of extremely gravelly medial loam (60 percent gravel, 5 percent cobbles, and moderately acid with a pH of 6.0), while that of Bogachiel extends only half as deep and is extremely gravelly medial sandy loam with the same percent of gravel and cobbles but more acid (5.6 pH). The lower horizons of both extend to similar depths (62-63 inches) but the B and C horizons of the Bogachiel series contain smaller percentages of gravel and larger percentages of sand and cobble and are slightly more acidic than those of the Ishmael series. The O horizon for the Duskpoint series is 0 to 1 inch, composed of slightly decomposed needles, leaves and twigs, and the A horizon is 1-6 inches, dark brown, very gravelly medial loam (50 percent gravel), and strongly acid with a pH of 5.4. The B and C horizons are extremely gravelly sand reaching to 61 inches (National Cooperative Soil Survey 2000).

Table 1. Plot sizes and locations.

Plot number	Radius (m)	½ plot radius (m)	Transect 10 radius (m)	Size (ha)	Location
11	12.62	8.92	17.85	.05	Restoration Unit
12	12.62	8.92	17.85	.05	Restoration Unit
13	12.62	8.92	17.85	.05	Restoration Unit
14	12.62	8.92	17.85	.05	Restoration Unit
15	12.62	8.92	17.85	.05	Restoration Unit
16	12.62	8.92	17.85	.05	Restoration Unit
17	12.62	8.92	17.85	.05	Restoration Unit
18	12.62	8.92	17.85	.05	Restoration Unit
19	12.62	8.92	17.85	.05	Restoration Unit
20	12.62	8.92	17.85	.05	Restoration Unit
21	12.62	8.92	17.85	.05	Restoration Unit
22	12.62	8.92	17.85	.05	Restoration Unit
23	12.62	8.92	17.85	.05	Restoration Unit
24	12.62	8.92	17.85	.05	Thinned Unit
25	12.62	8.92	17.85	.05	Thinned Unit
26	12.62	8.92	17.85	.05	Thinned Unit
27	12.62	8.92	17.85	.05	Thinned Unit
28	12.62	8.92	17.85	.05	Old Growth
29	12.62	8.92	17.85	.05	Old Growth
30	12.62	8.92	17.85	.05	Old Growth
31	12.62	8.92	17.85	.05	Old Growth
32	12.62	8.92	17.85	.05	Old Growth
33	12.62	8.92	17.85	.05	Cut Old Growth
34	12.62	8.92	17.85	.05	Cut Old Growth
35	12.62	8.92	17.85	.05	Cut Old Growth
36	12.62	8.92	17.85	.05	Cut Old Growth
37	12.62	8.92	17.85	.05	Cut Old Growth
38	12.62	8.92	17.85	.05	Cut Old Growth
2118	16.55	11.70	23.40	.086	Cut Old Growth
2506	16.55	11.70	23.40	.086	Cut Old Growth
2509	11.29	7.98	15.96	.04	Old Growth
2511	11.29	7.98	15.96	.04	Restoration Unit
2512	11.29	7.98	15.96	.04	Restoration Unit

STUDY DESIGN

This thesis project is part of a larger demographic study conducted by the Olympic National Forest Pacific Northwest Research Station in Tumwater, WA. The purpose of the study as a whole is to determine the response of low-elevation beargrass to natural light levels in terms of its demography, aboveground biomass and characteristics that are commercially important in its role as a non-timber forest product. The main study is similar to that of Higgins et al (2004), using a similar protocol to measure many of the same morphological characters. Whereas their study used percent canopy cover as the independent variable and was conducted in the more-studied montane habitat of the Cascade Range, the current study examined the levels of photosynthetically active radiation (PAR)-- the 400-700 nm spectral region which drives photosynthesis-- reaching the plants and was conducted in an atypical, possibly distinct (Maule, 1959), low-elevation habitat.

The general approach is to measure individual plants and plant parts in belt transects associated with an existing random plot network extending across a natural light gradient from forested to open areas. For the purposes of my study, rates of flower production, rhizomatous vegetative reproduction through the formation of offsets or creation of new meristematic tissue (centers), and morphological characteristics--such as length, width, and pigmentation-- that make it suitable for its traditional cultural uses by indigenous weavers (which are often at odds with its commercially-desirable qualities) will be examined.

Research Questions

1. What light levels are optimal for flower production and asexual reproduction via formation of new offsets?

2. Are the post-fire conditions in the restored unit producing plants that are superior for traditional cultural uses in basketry?

HYPOTHESES

1. Flowering, recruitment of seedlings and asexual reproduction will increase with greater levels of Photosynthetically Active Radiation (PAR).

2. There will be a difference in leaf morphology (length and width) across a light gradient among the plots and within the four treatment or stand types (two restored and two forested units).

METHODS

Transects

Figure 11. Laying out Transect 1, Plot 28.

In June 2014, 10 m^2 belt transects were laid out within each plot near the outer edge in the NE, SE, SW and NW quadrants (Figure 12). Beginning with the north cardinal point of the plot and proceeding in a clockwise direction, a tape measure was stretched between the cardinal points and 1 x 10 m belt transects were established at the 3.92 m mark, proceeding another 10 m to the end of the transect and the corners marked with red flags. Transects were then divided into thirds at the 1.7, 5.0 and 8.3 m marks. This was repeated in each quadrant and transects within the plots were numbered 1-4 beginning with the NE quadrant and continuing clockwise. Four additional transects were established outside the ecoplots parallel to those within the inner whorl of the ecoplot at a distance of 4.7 m from the outer border of the corresponding inner transect. Beginning with the NE transect, these were numbered 5-8. Preliminary reconnaissance in May 2014 revealed that density was much lower in the restoration plots and thus it could be necessary to add more area in order to obtain an adequate sample size. In these cases, the entire NE ¼ of the ecoplot was utilized and designated as "transect 9."

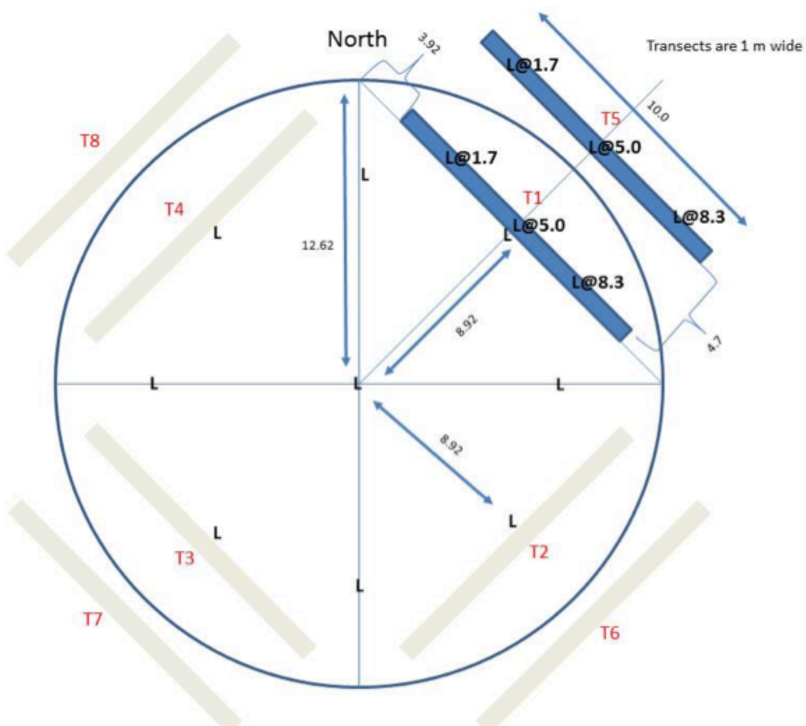

Figure 12. Plot and transect configuration and measurements. Light measurements (L) for the circular plot were taken at plot center, 8.4 m from the center, and at the center of each transect 1/3. Transect locations are 8.92 m from the plot center. The number of each transect is given in red. Diagram, David Peter 2014.

Light Measurements

Light measurements for percentage of photosynthetically active radiation (PAR) reaching the entire plot were made on cloudless days between 10:00 a.m. and 2:00 p.m. solar time (11:00 a.m.

and 3:00 p.m. PDT) July 1-17, 2014 using a Decagon AccuPar LP-80 ceptometer (Decagon Devices, Pullman, WA). Measurements were taken dbh (1.3 m) at the ½ point plot radius (Figure 12), which for most plots was at 8.9 m from plot center at 0, 45, 90, 135, 189, 225, 270 and 315 degrees, as well as at the plot center point. Light measurements were also taken over the demography transects (1-4) and biomass transects (5-8) at the 1.67, 5, and 8.33 m marks at 50 cm above the ground. Measurements were taken while standing north of the instrument with the instrument held level and pointing south. For the transect measurements, the instrument was centered on the midline of the transect. Full sun (above canopy) measurements were recorded immediately before each set of plot and transect measurements.

Demography

From July-September, 2014 beargrass plants were counted in the non-destructive (1-4, within the plot) and biomass sampling (5-8, outside the plot) transects. Beginning in the NE transect (1), plants were counted and marked with flags. All plants within transects 1 and 5 were counted. To be counted as within a plot, the center whorl of leaves, representing the current season's growth must fall within the transect. A plant was considered to be a single plant if it was a continuous clump (tussock) or chain of rosettes within 10 cm of another rosette, on the assumption that beargrass rhizomes can travel up to 10 cm. If fewer than 10 plants were found in the first transect, we proceeded to the first 1/3 of transect 2 (or 6) until a sample of at least 10 plants was attained. All plants were counted within an entire 1/3 even if the sample size went

Figure 13. Taking leaf length measurements in the Cut Old Growth Unit.

over 10. In the Restoration and Thinned units it was necessary to locate plants off transect to order to achieve an adequate sample, as density was much lower and few plants were located within the transects themselves in these plots.

Three random leaves from each plant were chosen representing both the inner (new growth) and outer (past seasons' growth) whorls. The leaves were pulled at the base and their length (cm) and width at the base and midpoint were recorded using a meter stick and calipers, respectively. The number of offsets from the rhizome, representing new sections of meristematic growth (hereafter referred to as "centers") was counted. The number of old flowering stalks still attached to the tussock and new flowering stalks were recorded and the length (cm) and basal diameter (mm) of living flower stalks noted. Because 2014 was not a heavy flower-producing year, it was necessary to incorporate data from the biomass transects in the restoration units in order to produce a sample size comparable to those of the transects associated with plots in the woodland units. From the biomass sampling transects, two leaves from the leaf area sample were selected to determine hue, value and chroma utilizing the Munsell Plant Tissue Color Book (Killmorgen Instruments Corporation, New Windsor, NY).

Figure 14. Beargrass plant in the Restored (burned) unit showing current season's flower stalk and old flowering stalks.

DATA ANALYSIS

Data were analyzed using RStudio (RStudio version 3.1.0) and Microsoft Excel (Microsoft Excel for Mac 2011, Version 14.4.9). Of the 784 plants surveyed, only 4 were found in the Thinned Unit; these were all in a single plot, three of which were located off-transect. The Thinned Unit was therefore not included in the statistical analysis on account of the small sample size and lack of sufficient information to achieve useful estimates. PAR measurements correspond to 659 plants to the nearest transect third, while 121 plants in the Restoration Unit (those in transects 9 and 10) do not have obviously nearby PAR values. For those plants the mean PAR of the plot was used for transect 9 and the means of transects 5-8 was used for transect 10. To account for uncertainty in the PAR analysis, PAR values were included from the most representative set but downweighted inversely proportionally to the number of PAR other PAR values for the given plant. The number of plants per treatment area is found in Table 2. Data were analyzed on the individual plant level in relationship to its corresponding PAR measurement, on the plot mean level and on the unit level.

In the analysis of vegetative reproduction it was deemed that a log transformation of the number of centers per plant would be a more useful method, as there were many plants with few centers and relatively few with many centers. Linear regression and ANOVA analysis were conducted for the variables of leaf length, leaf width and log number of centers. In both the ANOVA and linear model analysis, "random effects" were incorporated for each plot to account for correlation of plants within plots. Because the distribution of the log number of centers appeared skewed, an additional non-parametric Kruskal-Wallis test for the number of centers was performed. The proportion of plants flowering was analyzed using a Pearson's Chi-square test.

Table 2. Number of beargrass plants associated with plots in each treatment area.

	On Transect	Off Transect	Total
Old-growth	332	0	332
Cut Old-growth	284	0	284
Restoration Unit	43	121	164
Thinned Unit	1	3	4

RESULTS

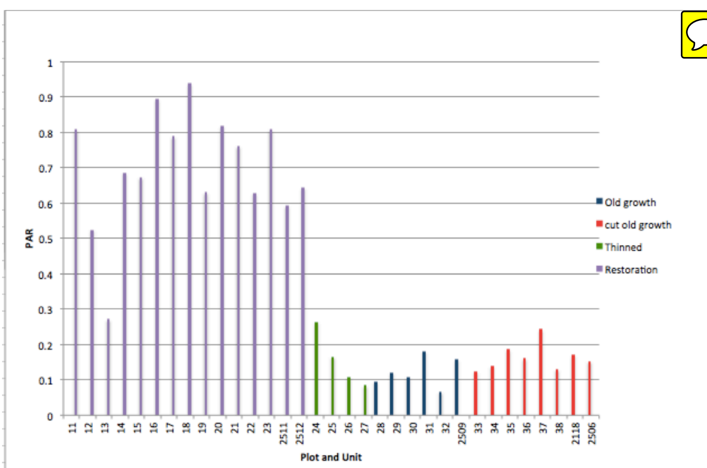

Figure 15. Mean PAR for plots by stand class (treatment)

Rather than seeing a gradient of light levels between the plots, PAR readings fell into two broad categories: greater than .500 and under .300. All plots with plot means greater than .500 were in the restoration unit and only one plot in the restoration unit was below .300 PAR (Figure 15). The plots in the Old Growth Unit had the lowest PAR on average while those in the Cut Old

Growth unit had slightly brighter conditions. The thinned unit is included for comparison, although no plants were found either on or off transect for three of the plots. The plot with the lowest PAR in the restoration unit was in a dense stand of alder (*Alnus rubra*) and also did not contain any beargrass.

Leaf Length

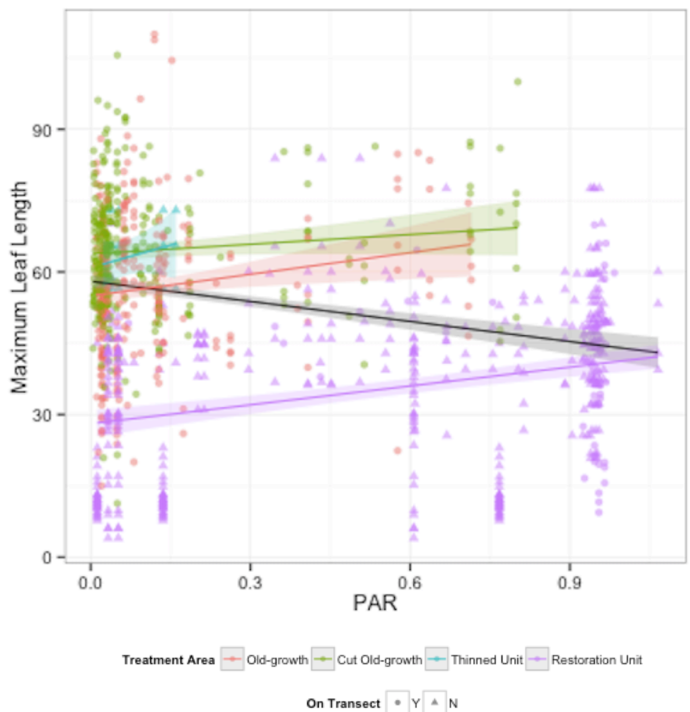

Figure 16. Longest leaf of plants regressed with corresponding PAR value.

Data were analyzed on the individual plant level with corresponding PAR values to the nearest transect third across the entire study site, on the plot level with individual plant measurements regressed with mean plot PAR, mean length within the plot regressed with mean plot PAR, and on the treatment unit level. Across the study site, the length of the longest leaves showed a negative correlation with PAR when analyzed with corresponding PAR values for individuals, however within each treatment unit there was a slight positive correlation between increased

PAR and leaf length (Figure 16.) Analyses of the mean longest leaf per plot regressed with mean PAR for the plot and for individual plant measurements with plot mean PAR also showed negative correlations, with the longest leaves found in the Cut Old Growth and the lowest means in the Restoration Unit (Figures 17 and 18). Incorporating the entire study site, a regression analysis of mean plot PAR and mean longest leaf per plot found a significant association ($p <$ .001) with an r^2 of 0.513, and an estimated decrease in average maximum leaf length of 3.18 per increase of mean PAR of 0.1 (Figure 18.)

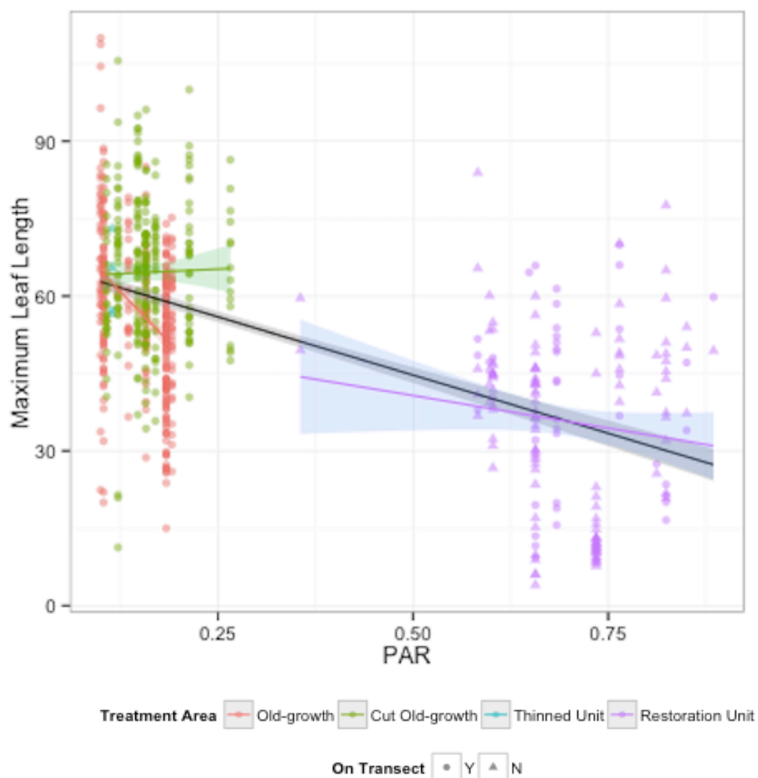

Figure 17. Longest leaf length of individual plants regressed with plot level mean PAR.

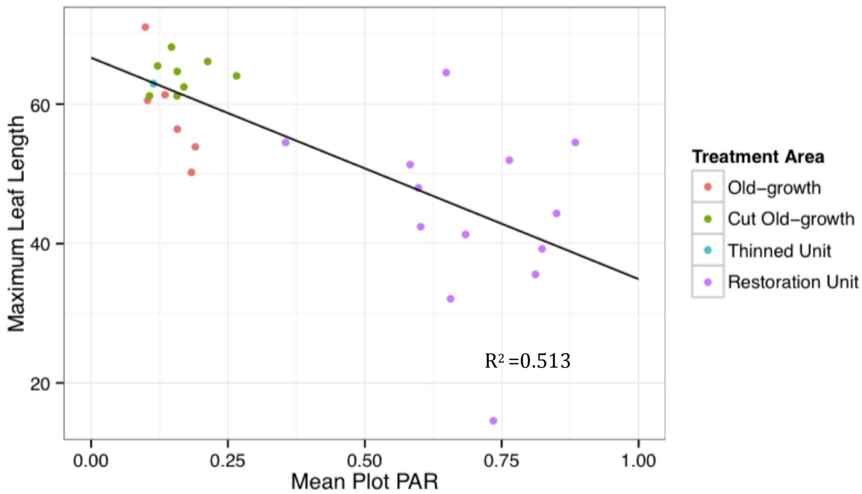

Figure 18. Comparison of mean longest leaf per plot and mean plot PAR.

Comparisons between the treatment units suggested there was a difference in maximum leaf length across treatment areas (Figure 19), which were confirmed by an ANOVA with random effects for each plot within the treatment area ($p < 0.001$). A linear model, controlling for the treatment area as a fixed effect and incorporating plots as random effects did not find a significant association between PAR and leaf length ($p = 0.138$). An increase in PAR by 0.1 is associated with an increase in leaf length of 0.309 (95% CI: 0.0992 to 0.717) (Figure 20).

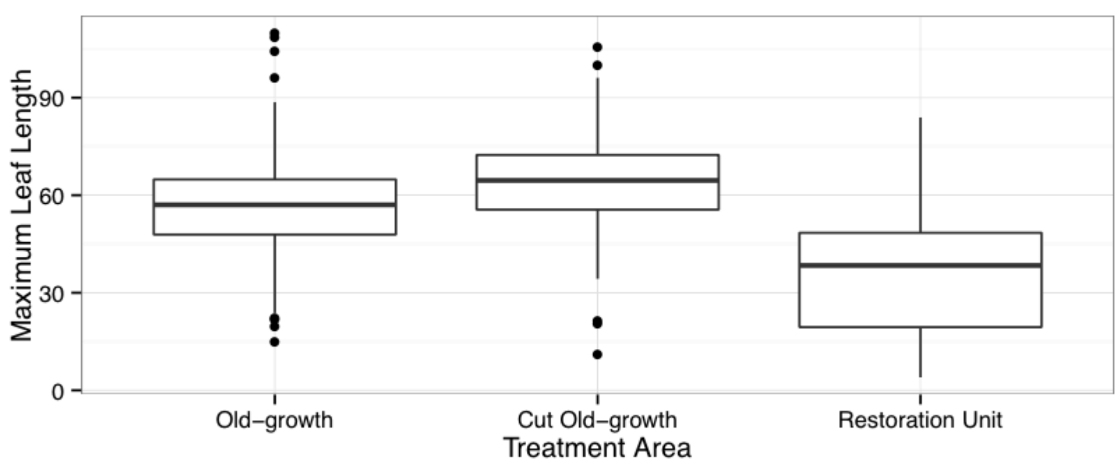

Figure 19. Comparison of beargrass longest leaf between treatment areas

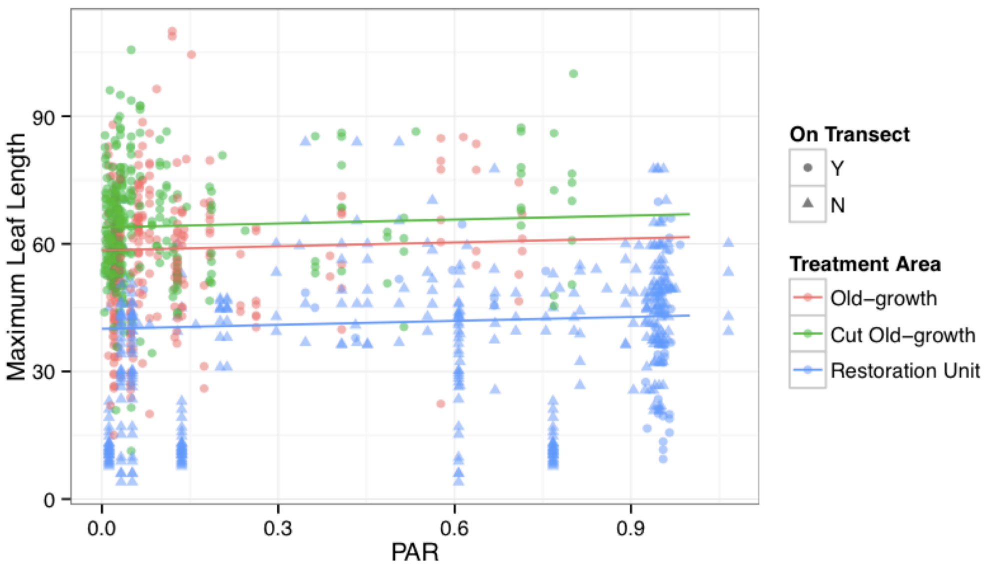

Figure 20. Leaf length by treatment area regressed with PAR

Leaf Width

Comparison of mean leaf width for individual plants with their associated PAR or with plot mean PAR throughout the study site did not show a clear trend and are shown in Appendices 1 and 2, box c. Mean leaf width appeared to increase with PAR in the Cut Old Growth, increase slightly in the Old Growth and had a slightly negative trend in the Restoration Unit. On the plot level, results of the regression analysis showed an estimated increase of PAR of 0.1 is associated with an increase of 0.0141 in mean leaf width (95% CI: decrease of 0.0415 to an increase of 0.0697) and the association was not significant ($r^2 = 0.0104$) (Figure 21).

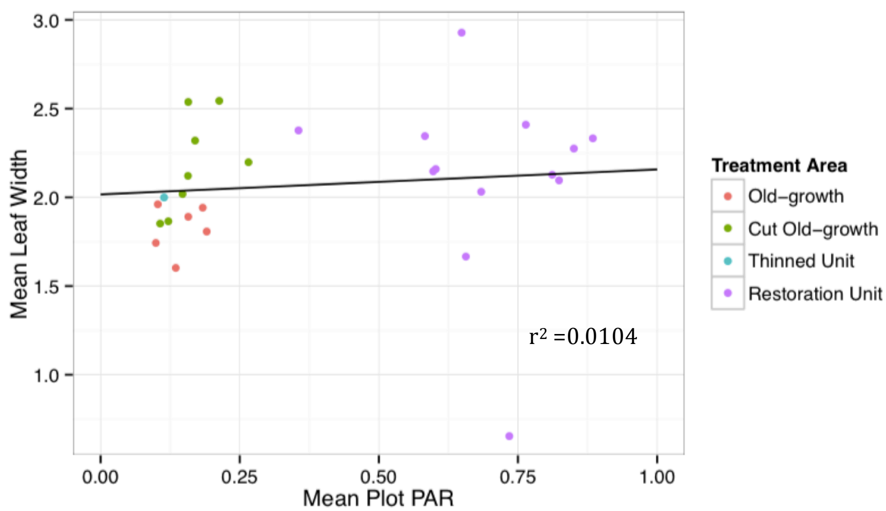

Figure 21. Comparison of mean width of leaves of all plants within a plot to the mean PAR

Looking at mean leaf width across the different treatment units, there does not appear to be a difference in the boxplot analysis (Figure 22), which was confirmed by the ANOVA analysis (incorporating plots as a random effect) (p = 0.239).

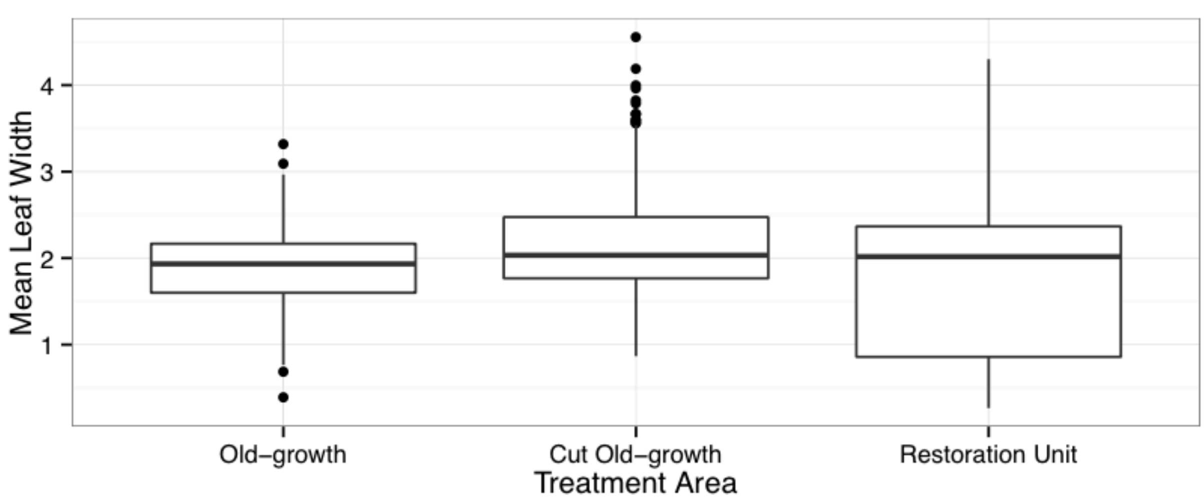

Figure 22. Comparison of mean leaf width of beargrass leaves across treatment units.

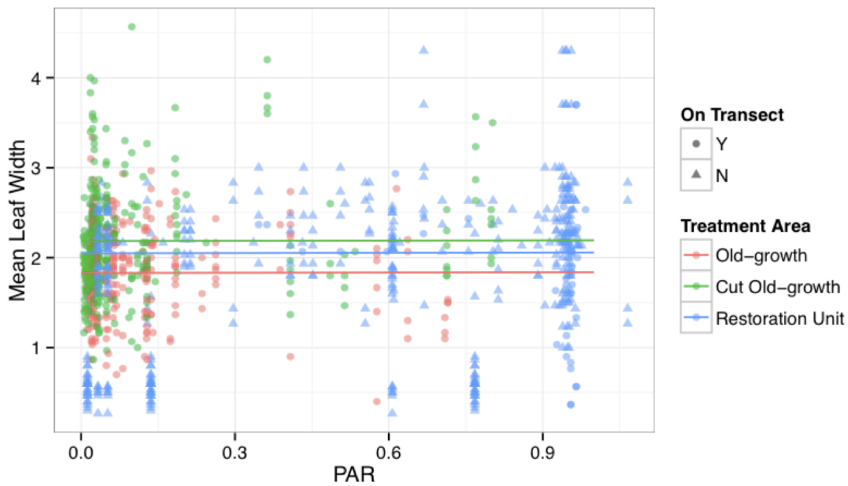

Figure 23. Linear regression of PAR and mean beargrass leaf width across plots in three treatment units.

A regression model was used to investigate the association between PAR and mean leaf width, controlling for the treatment area and again incorporating a random effect for each plot (Figure 23). From this, it is estimated that an increase in PAR of 0.1 is associated with an increase in mean leaf width of 9.05×10^{-4} (95% CI: 0.0157 to 0.0175), but the difference is not significant ($p = 0.915$).

Leaf Color

Table 3. Leaf color of beargrass across plots in the units with associated PAR levels. Data represents mean (*SD*).

UNIT	PLOT #	HUE *	VALUE *	CHROMA*	PAR
Restoration (Burn)	11	5gy *(0)*	4 *(0)*	6 *(0)*	0.92505 *(0)*
	12	5gy *(0)*	4 *(1.41)*	6 *(0)*	0.43723 *(0)*
	14	5gy (*0*)	4.5 (*0.53*)	5 (*1.07*)	0.42582 *(.34196)*
	15	5gy *(0)*	4 *(0)*	6 *(0)*	0.61281 *(0)*
	16	5gy *(0)*	4 *(0)*	4 *(0)*	0.80563 *(.12429)*
	17	3.75gy *(1.77*)	5 *(0.94)*	5.6 *(0.84)*	0.74411 *(.38097)*
	19	3.75gy *(1.44)*	4.5 *(0.58)*	6.5 *(1)*	0.66754 *(0)*
	20	4.82gy *(1.54)*	4.93 *(0.73)*	5.86 *(1.46)*	0.94243 *(.00794)*
	22	5gy *(0)*	4.83 *(0.75)*	5.67 *(0.82)*	0.96531 *(0)*
	23	4.58gy *(1.02)*	4.5 *(0.84)*	5.67 *(0.82)*	0.3052 *(.40512)*
	2511	5.42gy *(1.02)*	3.83 *(0.41)*	4.33 *(0.82)*	0.42845 *(.07987)*
	2512	4.38gy *(1.16)*	5.13 *(0.64)*	6.25 *(1.67)*	0.77356 *(.3621)*
Restoration (Thinned)	25	6.25gy *(1.77)*	4 *(0)*	5 *(1.41)*	0.02227 *(0)*
Cut Old Growth	33	6.25gy *(1.37)*	3.67 *(0.82)*	4.33 *(0.82)*	0.005 *(.00114)*
	34	5.42gy *(1.02)*	3.67 *(0.52)*	4 *(0)*	0.03153 *(0)*
	35	5.83gy *(1.29)*	3.67 *(0.52)*	4.67 *(1.63)*	0.50938 *(.25368)*
	36	5.42gy *(1.02)*	3.5 *(0.55)*	4 *(0)*	0.07323 *(.0441)*
	37	6.67gy *(1.29)*	3.17 *(0.41)*	4 *(0.82)*	0.07302 *(.06775)*
	38	5.42gy *(1.88)*	4.5 *(0.84)*	5.33 *(1.63)*	0.04991 *(0)*
	2118	5.83gy *(1.29)*	3.67 *(0.52)*	4.33 *(0.82)*	0.01795 *(0)*
	2506	6.67 *(1.29)*	3.33 *(0.52)*	5 *(1.03)*	0.76916 *(0)*
Old Growth	28	7.5gy *(0)*	3 *(0)*	4 *(0)*	0.01468 *(0)*
	29	5.42gy *(1.02)*	3.83 *(0.41)*	4 *(0)*	0.20314 *(.15707)*
	30	5gy *(0)*	3.83 *(0.41)*	4.33 *(0.82)*	0.02569 *(.02569)*
	31	5.83gy *(1.29)*	3.67 *(0.52)*	4 *(0)*	0.04539 *(.02196)*
	32	5.42gy *(1.02)*	4 *(0)*	4 *(0)*	0.02775 *(0)*
	2509	5.42gy *(1.02)*	4 *(0.63)*	5 *(1.1)*	0.14009 *(0)*

***Hue is the general color, e.g. green, green-yellow, yellow, etc.; value is the degree of lightness or darkness relative to a grey scale with 0 as black and 10 as white; chroma is the saturation of color with 0 representing neutral grey and higher values representing increasing degrees of saturation.**

Leaf color did not undergo statistical analysis, but hue, value and chroma were all averaged for leaves sampled within the biomass transects of each plot and are listed in Table 3 with the associated plot mean PAR and grouped by unit (Figure 24).

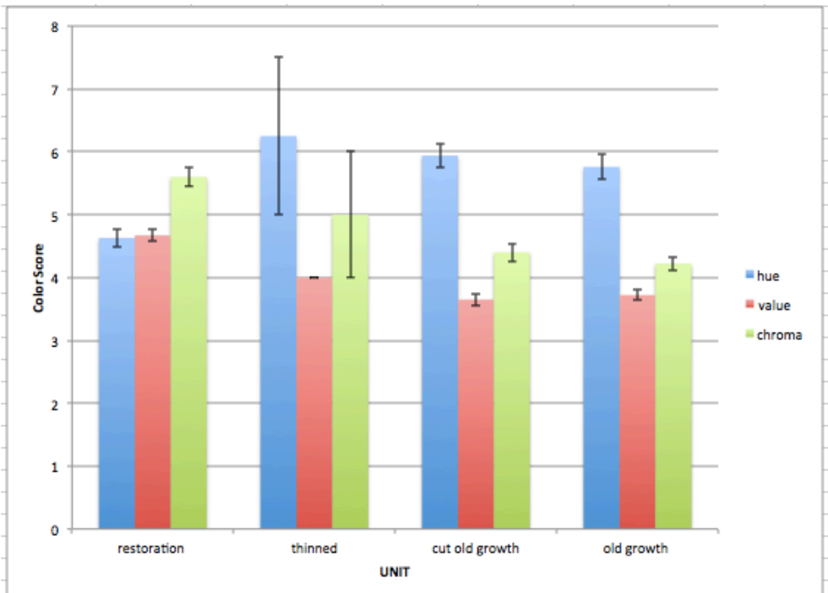

Figure 24. Means of the analyses of hue/value/chroma of beargrass leaves in the treatment areas.

Hue and value are the most important characteristics, which show the color on the spectrum wavelength and the relative darkness to lightness on a greyscale, respectively. All leaves across the site had a hue in the green yellow range (yg) but leaves in the restoration unit showed on average more yellow and the wooded units more green. The Restoration leaves ranged from 2.5 to 7.5 with a mean of 4.62 (*n*=56) from 28 sampled plants. Leaves in the Cut Old Growth showed a range of 2.5 (a single leaf) to 7.5 with a mean of 5.93 (*n* = 50), while leaves in the Old Growth unit displayed a range of 5 to 7.5 and a mean of 5.76 (*n*= 34). Value in the Restoration leaves ranged from 4 to 6 *(m* = 4.67); in the forested units, range was 3 to 5 (*m* = 3.65) in the Cut Old Growth and 3 to 4, with a single plant exhibiting a 5 in the Old Growth (*m* = 3.72).

Chroma represents the amount of color saturation, with a 1 indicating neutral grey, increasingly becoming more saturated in the color. There was over a point difference in chroma between the Restored unit and the forested units, with leaves in the Restoration showing more saturation in the 4 to 8 range (*m* = 5.57), while the Cut Old Growth and Old Growth Units exhibited ranges and means of 4 to 8 (4.42) and 4 to 6 (4.22), respectively.

Vegetative Reproduction

Vegetative reproduction was quantified on the basis of the number of offshoots (centers) from the rhizome a plant produces. To stabilize the variance in counts, a log transform was performed. A boxplot comparison of the log number of centers suggested a difference between units with the Restoration Unit showing a larger number of centers, as expected, than either forested unit. (Figure 25). Results of an ANOVA indicated a significant difference between the log number of centers per plant between units ($p < 0.001$), which was confirmed by an additional non-parametric Kruskal-Wallis test because of the skewedness of the distribution ($p < 0.0001$)

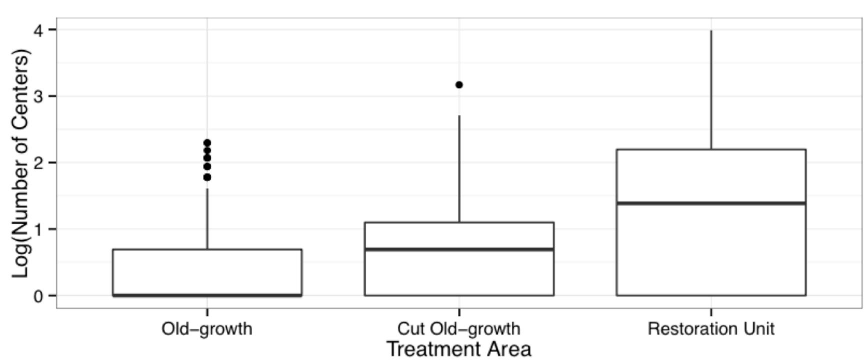

Figure 25. Comparison of mean log(number of centers) among treatment areas

When analyzing the association between PAR and the number of centers per plant, there appears to be a conflict between the results for the plot level and the results for the individual plants and their associated PAR within each unit. Looking at the association on the plot level, there appears to be a positive correlation between PAR and number of centers (Figure 26.) The regression obtains a r^2 of 0.472 and finds the association to be significant ($p < .0001$). From this, it is estimated that an increase in mean PAR of 0.1 is associated with a 22.3% increase in the average number of centers per plant. However, in examining the association on individual plants on plots within each unit, the regression shows an apparent negative correlation (Figure 27).

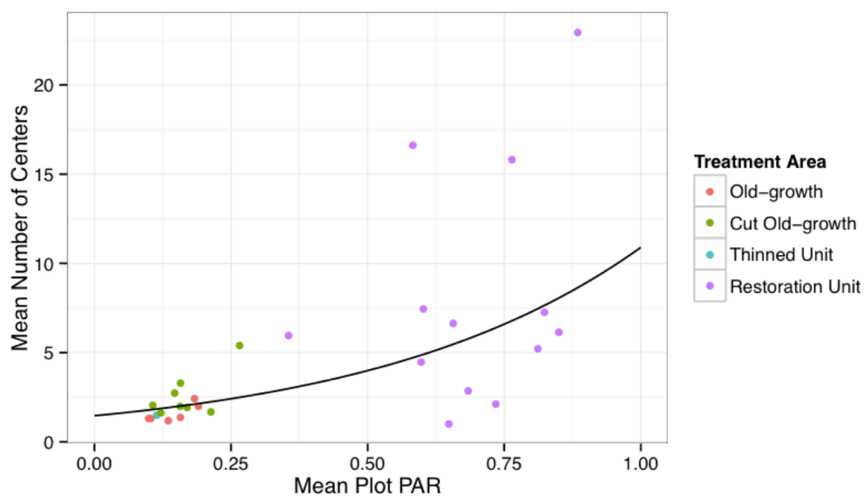

Figure 26. Regression of mean plot PAR and log(number of centers).

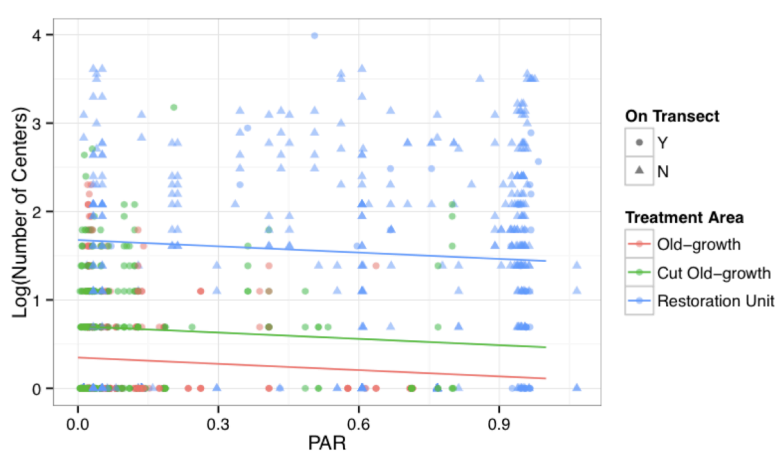

Figure 27. Linear regression of PAR and mean log number of beargrass centers across plots in three treatment units

Once again using the log transform of the number of centers per plant, controlling for treatment area and incorporating random effects for each plot, it is estimated that an increase in PAR of .01 is associated with a decrease in the number of centers within each unit (95% CI: 0.309% decrease to 4.33% decrease. Results were significant ($p = 0.0241$).

Flowering

Table 4. Proportion of beargrass plants across the treatment areas that show evidence of flowering in the current season or previous seasons via persistence of old flowering stalks.

	No Flowers	Evidence of Flowering		
		Current	Previous	Total With Flowers
Old Growth	324	1	8	8
Cut Old Growth	263	1	20	21
Restoration	82	17	65	82

Percent of sampled beargrass plants that either had the current season's senescent flower stalk with some evidence of persistent pedicels or seed capsules remaining was 50 % in the Restoration unit while only 7.39 % and 2.41% in the Cut Old Growth and Old Growth units each (Table 4). From the proportions of flowering plants we can expect to see a significant difference across treatment areas, which was confirmed by performing a Pearson's Chi-square test ($p < 0.001$).

While it was expected that increasing levels of PAR would predict greater numbers of flowers, a logistic mixed effects model analyzing the association of PAR and flowering across the units estimated a modest increase in the log odds of flowering of 0.0502 (95% CI: 0.106 to 0.206), which was not significant ($p = 0.529$), as shown in Figure 28.

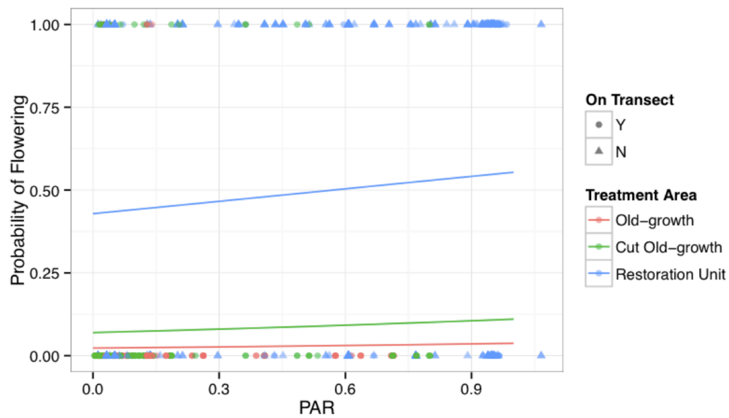

Figure 28. Linear regression of PAR and probability of flowering.

DISCUSSION

Leaf length

Across the study site, leaf length showed a decline with increasing light levels, which was expected. Sun leaves and shade leaves display different physiology, with those in dense shade expanding their leaf area and assuming a more horizontal orientation to allow for better light penetration. Further, plants under the denser canopy have been growing for a longer period in undisturbed conditions and may have accumulated more reserves in their rhizomes. However, another factor in the difference in leaf length between the treatments, is the presence of a large number of seedlings off-transect in the restoration unit in plots 23 and 2512 and their size class could have skewed the results. Seedlings were largely absent from the forested plots, though some were present on one plot in the Cut Old Growth.

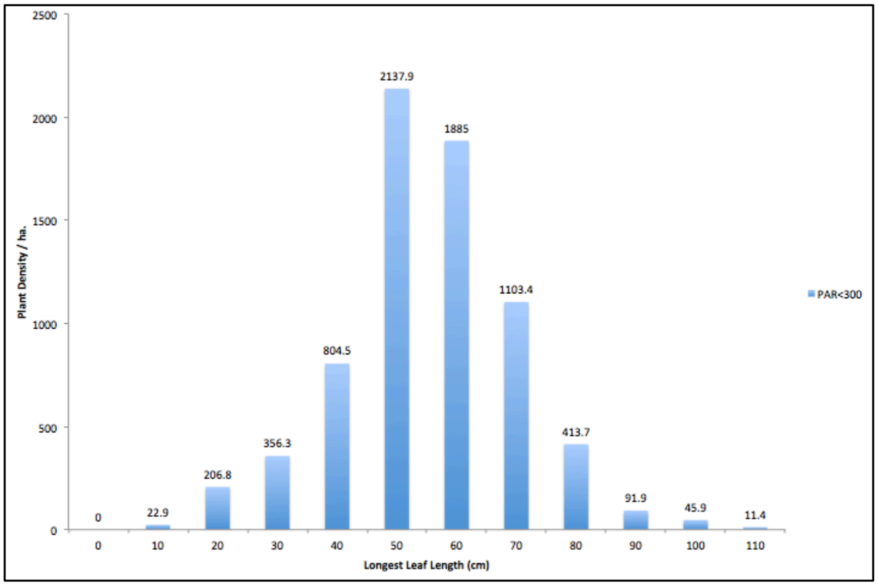

Figure 29. Distribution of densities in leaf length classes for the forested units.

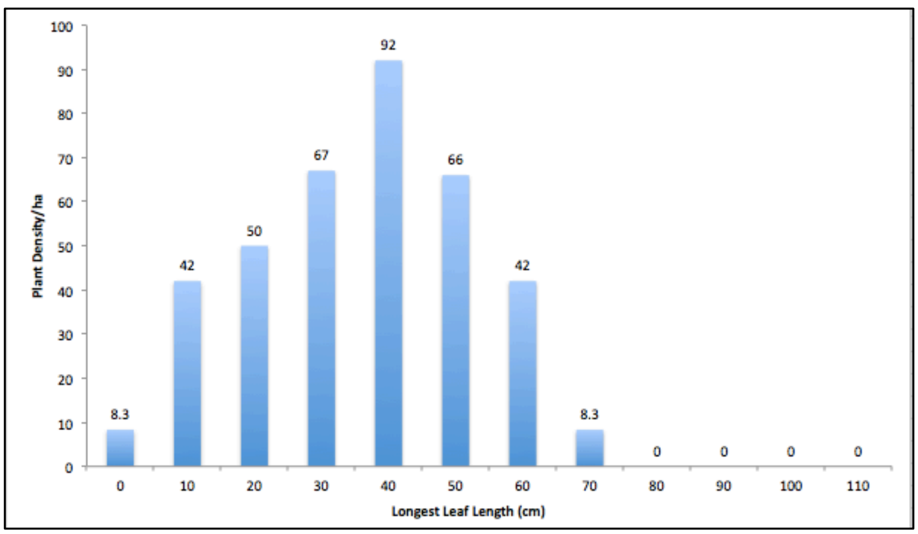

Figure 30. Distribution of densities in leaf length classes for the restoration unit.

Leaves sought by weavers are 2-3 feet in length (61-91 cm) (Jones 1977, Shebitz 2006). On plots under .300 PAR, percentage of plants with leaves of usable length is greater than that of plots over .300 PAR (53% vs 13%) and density is lower (Figures 29 and 30). From this perspective, lower light levels under current conditions are more beneficial. The Restoration is more open than it may have historically been. From native accounts, burning generally took place every 2-3 years and were slow-moving low-intensity fires that killed underbrush and conifer seedlings but did not eliminate the thick barked older trees (Peter and Shebitz, 2006). The fire in 2003, in contrast, burned hotter than expected because of a heavy fuel load left from the prior logging and a dense shrub understory, surpassing the melting point of aluminum (660˚ C) (David Peter, personal communication January 2015). The evidence of the soil sterilization is still evident in patches 11 after and some areas are still exposed. While conifers are regenerating in the burn, it may be that the unit has not had sufficient time to build up the partly shaded dappled canopy that produces the best leaves for weaving, suggested by the lack of a light gradient in the .300-.500 PAR gradient in any of the plots.

Leaf width

Increasing light level did not have a significant effect in leaf width. Determining the ideal leaf width for basketry appears to be subjective. Nordquist and Nordquist (1983) reported the width for larger Skokomish baskets was 1/4 to 1/8” (6.4 to 9.5 mm). At the same time, a narrower leaf is desirable for fine basket work, as the material can be woven closer together between a smaller warp (Rentz 2003). Tribal leader Justine James of the Quinault Nation, who assisted Daniela Shebitz with her doctoral research, estimated that it would be about 5mm (James, personal communication January 2015). It is likely that a master weaver would have his or her own preferences based upon the fineness of the weave and whether it was a twined or coiled basket and could cut the leaves to size.

To gain a better understanding of the width of fibers in Skokomish basketry, I measured beargrass fibers in 4 articles made prior to the 1930s from the Burke Museum's collection at the University of Washington with calipers. I took 5 measurements from different vertical planes of the basket so I would sample different fibers, as beargrass is typically used as a weft material, whereas the warp is often cedar root (Nordquist and Nordquist 1983). I took the mean of the fibers in each article to see if a particular width was preferred (Appendix _). Fibers ranged from 6.75 mm in a beargrass overlay basket to 1.62 mm in a bundle of raw material that was tagged by the collector as "Sample from gathering with Twana considered very fine and used for small and fine baskets." As most of these fibers were likely originally wider before having their sharp edges cut, I looked at the number of leaves that were sampled that were over 3 mm at the midpoint of the leaf. Of the 2352 leaves sampled, only 120 fit this category and none were the size needed for large basketry reported in Nordquist and Nordquist (1983). Beargrass leaves are strongly keeled at the midrib and it is possible that dried leaves lay flatter once the stiff midrib is removed and measure wider, the fibers came from a habitat with different soil conditions than the study site or canopy closure and overharvest are effecting leaf width.

While leaf width did not differ significantly between units or with increasing levels of PAR, post-fire conditions in the restoration unit may be more conducive to producing a thinner, more pliable leaf, which may be of greater importance to a weaver. Rentz (2003) observed that beargrass leaves growing in an area that had been burned had fewer rows of fibers below the adaxial epidermis and less sclerified tissue, resulting in greater elasticity. This is likely a more important factor in a weaver's choice of which leaves are suitable for harvest than width alone.

Leaf color

The preferred leaves for basketry are less pigmented, and thus bleach better and are more accepting of dyes. Furthermore, leaves that are yellowed are not used because they are more brittle. A study by Hummel and Lake (2015) that was published after this study began asked expert weavers from three western states to identify leaf properties from sites they deemed poor, marginal, and good to harvest beargrass leaves for basketry. Sites deemed "good for basketry" contained leaves with the highest frequencies of Munsell hue/value/chroma classifications in 5gy/4/4 and 5gy/4/6 with a mean of 5.08/4.14/4.95. Leaves that were 2.5yg were not selected, as they had too much yellow, nor were values below 3, which was infrequent, or above 7. In comparison, 66% of sampled leaves in the Restoration unit met these criteria, with 54 % would be acceptable in the Cut Old Growth and 44 % in the Old Growth. Although there were higher frequencies of a more yellow leaf in the Restoration, pigmentation was generally too dark with more canopy closure of the Old Growth. Thus, the higher light levels in the Restoration unit may be producing a leaf that is more conducive to bleaching and dying.

Vegetative reproduction

Results showing the negative correlation between vegetative reproduction and PAR across the study site were perhaps the most unexpected given the presence of plants with many centers in the Restoration unit. Resprouting at the base has been found to be stimulated by increased light at the plant base after a fire (Crane 1990, Rentz 2003, Shebitz et al 2009), but the most active regrowth is usually found in the 2-3 years following a fire and most studies have taken place in the 2-7 years following the burn (Rentz 2003, Shebitz et al 2009b). Rather than PAR alone, it is likely that other factors, such as reduced competition from the shrub understory, increased soil temperature, and return of nutrients to the soil from the burned vegetation, particularly increased availability of Nitrogen in otherwise nutrient-poor soils, have significant roles in regeneration.

Considering the more recent disturbance in the Restoration unit, it is reasonable to expect the plants found there are younger than the majority of those in the forested plots. A greater component of seedlings and young plants that have not yet built up reserves to form additional offsets could influence the results.

Because a large proportion of plants in the restoration were located off-transect without associated PAR readings, there is a reduction in precision for the restoration plots, which must be considered as well. Furthermore, we made an assumption that basal rosettes within 10 cm of one another in the two forest plots arose from the same rhizome. Without performing a destructive harvest, there is uncertainty of the size of the underground organ. It is possible that some of the plants that were recorded as having multiple centers were, in fact, separate plants.

Flowering

Previous research has indicated that beargrass does not flower under a dense overstory and needs sun for flower production (Vance et al 2001), thus it was unexpected that increasing levels of PAR did not lead to a significant likelihood of flowering. This study found that flowering is possible under very low PAR levels, though not as abundantly as in the open canopy of the Restoration. While it may be that variables, such as soil temperature (Shebitz et al 2009), play a larger role than PAR in the probability of flowering, I believe that the low significance may be affected by a weakness in the chosen method of evaluation. The analysis of flowering did not account for plant size. The mean for plants with evidence of past or current flowering in the Restoration unit that had direct PAR measurements to the plot-third level was 0.81995, but there were also many plants growing under PAR levels of .800 or above that were small and perhaps had not acquired enough resources for allocation of photosynthate to flower production.

Beargrass in some habitats is thought to flower in 5 to 7 year cycles, while in others blooming occurs annually but sporadically in the population (Maule 1959, Crane 1990, Vance et al. 2001). To my knowledge, rates of annual flowering have not been studied long-term in this location so it is unknown if large flushes of blooming occur in cycles, though the presence of an albeit small percentage of flower stalks suggests there is some flower formation annually. Of the 17 plants associated with plots that had flowered the year of this study, 89 % were found in the Restoration unit as well as 70 % of plants in which past flowering was evident from the persistent dry flower stalk. Further examination of data points for those plants which had flowered in the two forested units did not indicate that most of these plants were growing in bright sunflecks created by canopy gaps. The mean PAR associated with these plants was 0.16052, ranging from 0. 0137 to 0.79961, with the median being .05827 (standard deviation 0.205). It is likely that data from these individuals influenced the results of the analysis on the effects of PAR on probability of flowering on the study site as a whole, particularly given the relatively small sample size.

Recruitment of new seedlings can be one indication of a growing population. Beargrass seedlings when very young often look like small *Carex*, which were also present in the burned area, can be distinguished by a gray-white bloom (Maule 1959) and, by touch, from the serrations on the margins. The presence of a large number of seedlings, defined as plants with maximum leaf length under 15 cm, associated with plots 23 and 2512 in the Restoration unit can be viewed as an encouraging sign that the population is regenerating via sexual reproduction. Beargrass flowers are self-incompatible, meaning that they recognize and reject the pollen deposited by an insect visiting the same inflorescence and must be cross pollinated (Vance et al 2004). If one makes the assumption that the population is genetically varied, the remixing of alleles may confer greater fitness on the population in the event of disturbances such as climate fluctuations than vegetative reproduction alone (Vance et al 2004).

Figure 41. Beargrass seedling

Again, there may be other factors that are of greater significance to beargrass flowering and seedling recruitment. As a plant that has evolved with and adapted to fire, chemical compounds from the smoke and the burned vegetation have been shown to facilitate germination, though the effects were not as pronounced in seed collected from populations in the southeastern Olympic Peninsula as they have been in other lowland habitats on the coast (Shebitz et al, 2009a).

Areas for further research

Below-ground biomass was a variable that was not looked at in this study but would provide understanding into resource allocation of beargrass plants after release from canopy closure. Furthermore, little research has been done into the longevity of an individual beargrass rhizome. In the two forested units, we made an assumption that mid- to larger diameter whorls that were separated by less than 10 cm were produced from the same rhizome, yet the whorls of centers growing in the restoration unit were much more tightly clustered. Furthermore, it is likely that many of the larger diameter plants in the Cut Old Growth and Old Growth units have persisted there for many years when the system was maintained in a more open savanna structure. It is unknown whether the rhizome elongates and produces new centers at greater distances than those in brighter environments or how often new offshoots are formed.

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The best beargrass has been reported in the partial shade of the periphery of the open areas. Perhaps this is the intersection between longer leaf length and lighter pigmentation without the yellowish coloration and should be the desired structure when managing the area if the provision of a cultural resource is the desired result.

SUMMARY AND CONCLUSIONS

In conclusion, the effects of light level on the cultural qualities of beargrass were not as strong as expected. Except for the decline in leaf length, there were not significant changes with increasing PAR on the site taken as a whole, although significant differences between units for found for leaf length and vegetative reproduction. The best beargrass has been reported in the partial shade of the periphery of the open areas. Perhaps this is the intersection between longer leaf length and lighter pigmentation without the yellowish coloration and should be the desired structure when managing the area if the provision of a cultural resource is the desired result.

This study is meant to nest into the larger beargrass savanna demographic study that investigates a number of additional variables such as percent canopy cover by species, crown height, crown and basal diameter, leaf density, and above-ground biomass that are not reported here. It was my aim to examine how light levels in the restoration unit and in the former savanna that has been densely overtopped by trees may be impacting morphological characteristics of importance to the Skokomish people that had long tended and maintained this habitat as a cultural resource. Further, I hoped to gain insight into the regeneration potential of beargrass 11 years after the prescribed burn. It is hoped that data from this study will serve as a baseline measurement for any new burns that may occur in the future and that research will continue concerning how long post-fire benefits to beargrass plants will last and how to find and maintain the optimal stand structure.

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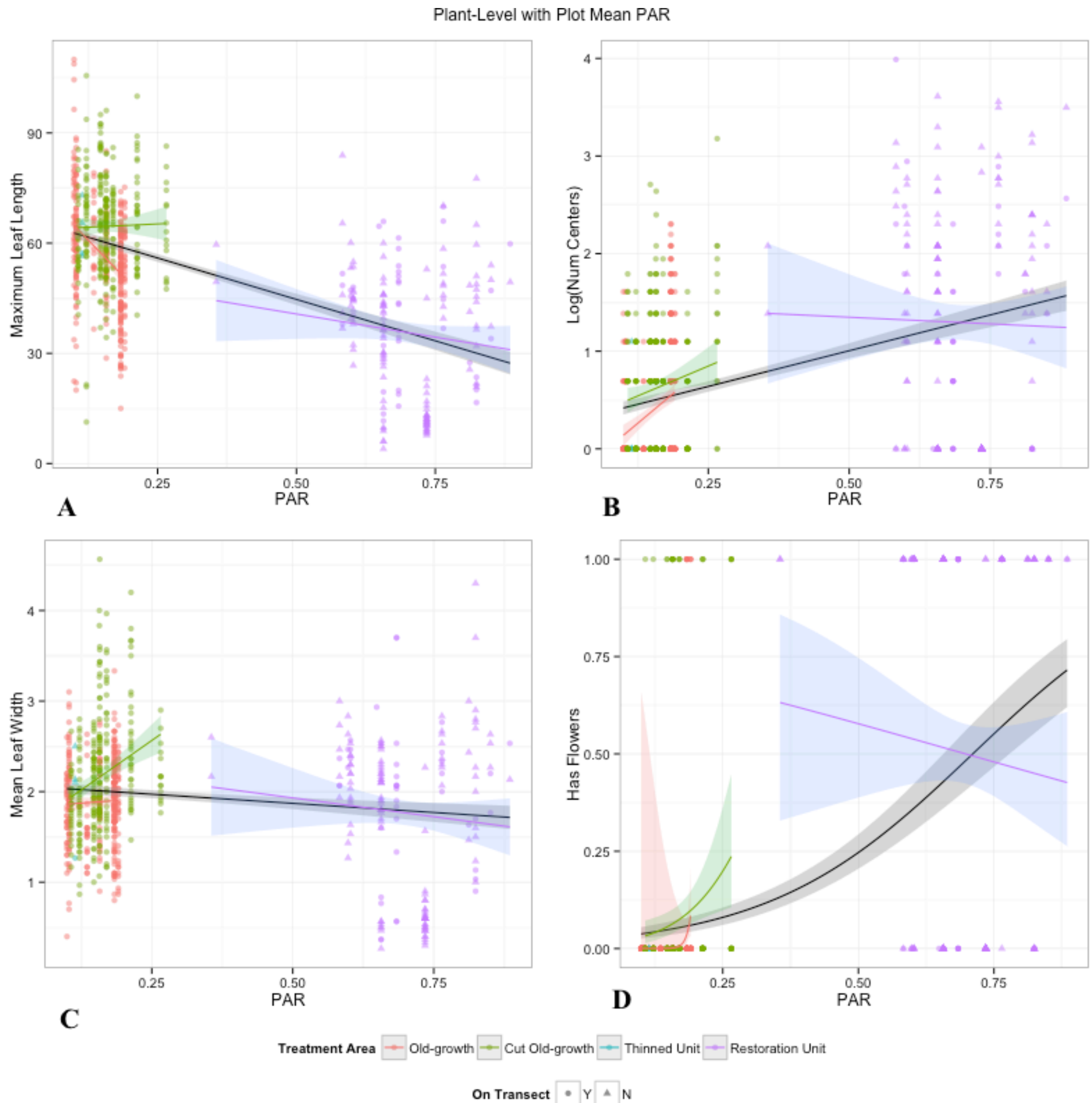
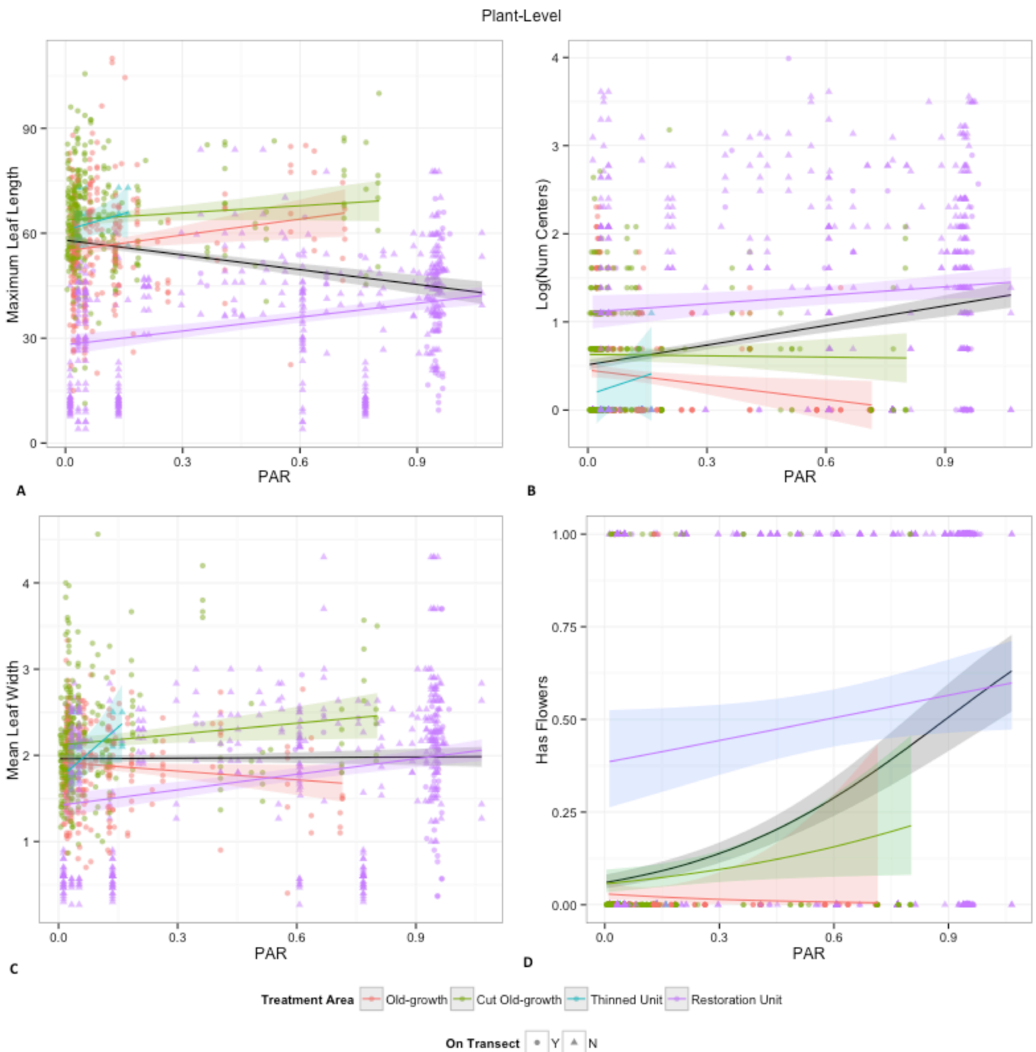
APPENDIX



Plant-Level with Plot Mean PAR
Maximum Leaf Length
Log(Num Centers)
Mean Leaf Width
Has Flowers
PAR
A
B
C
D
Treatment Area
Old-growth
Cut Old-growth
Thinned Unit
Restoration Unit
On Transect
Y
N


Plant-Level
Maximum Leaf Length
PAR
A
Log(Num Centers)
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Mean Leaf Width
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Has Flowers
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Treatment Area
Old-growth
Cut Old-growth
Thinned Unit
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On Transect
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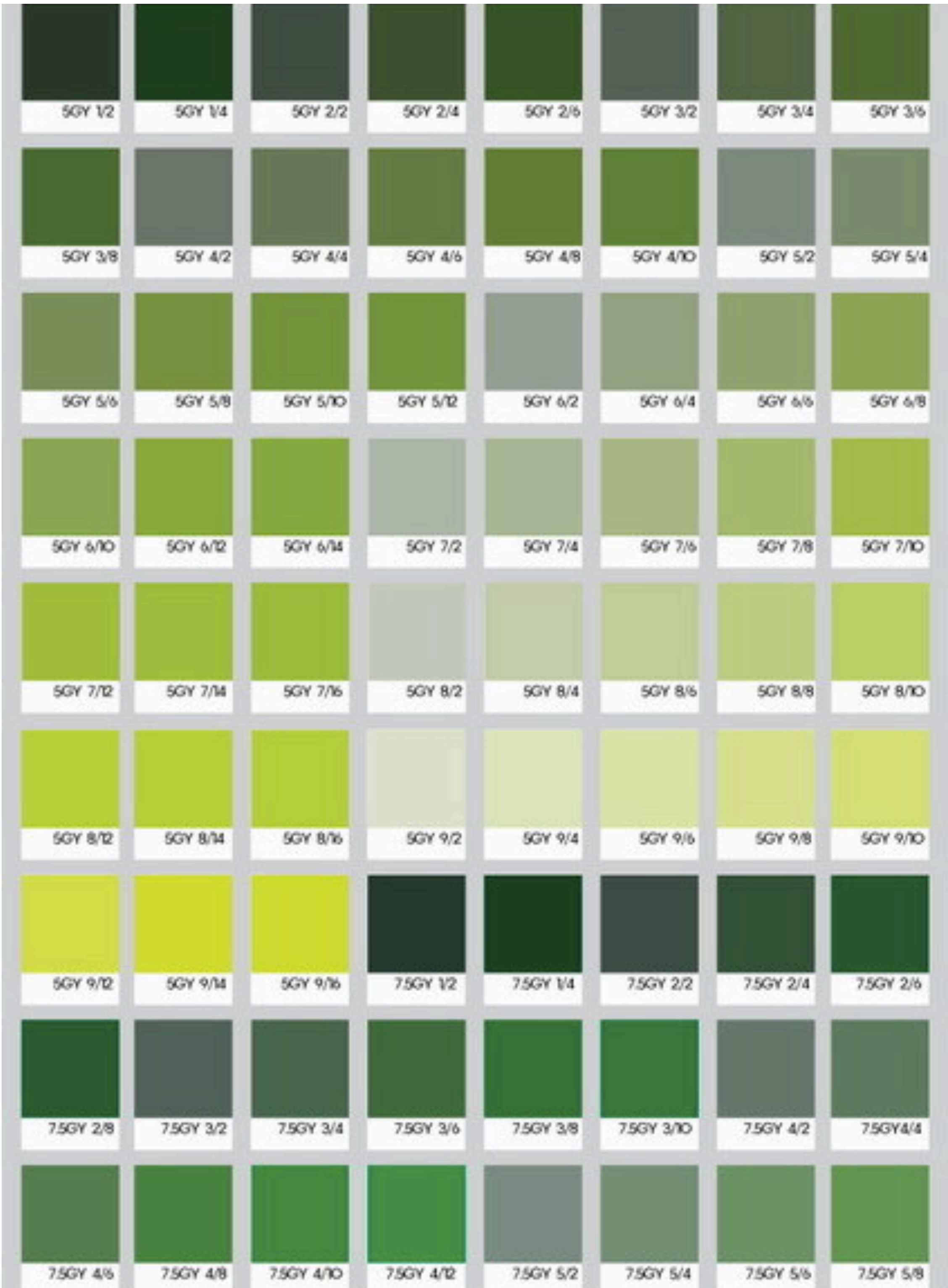
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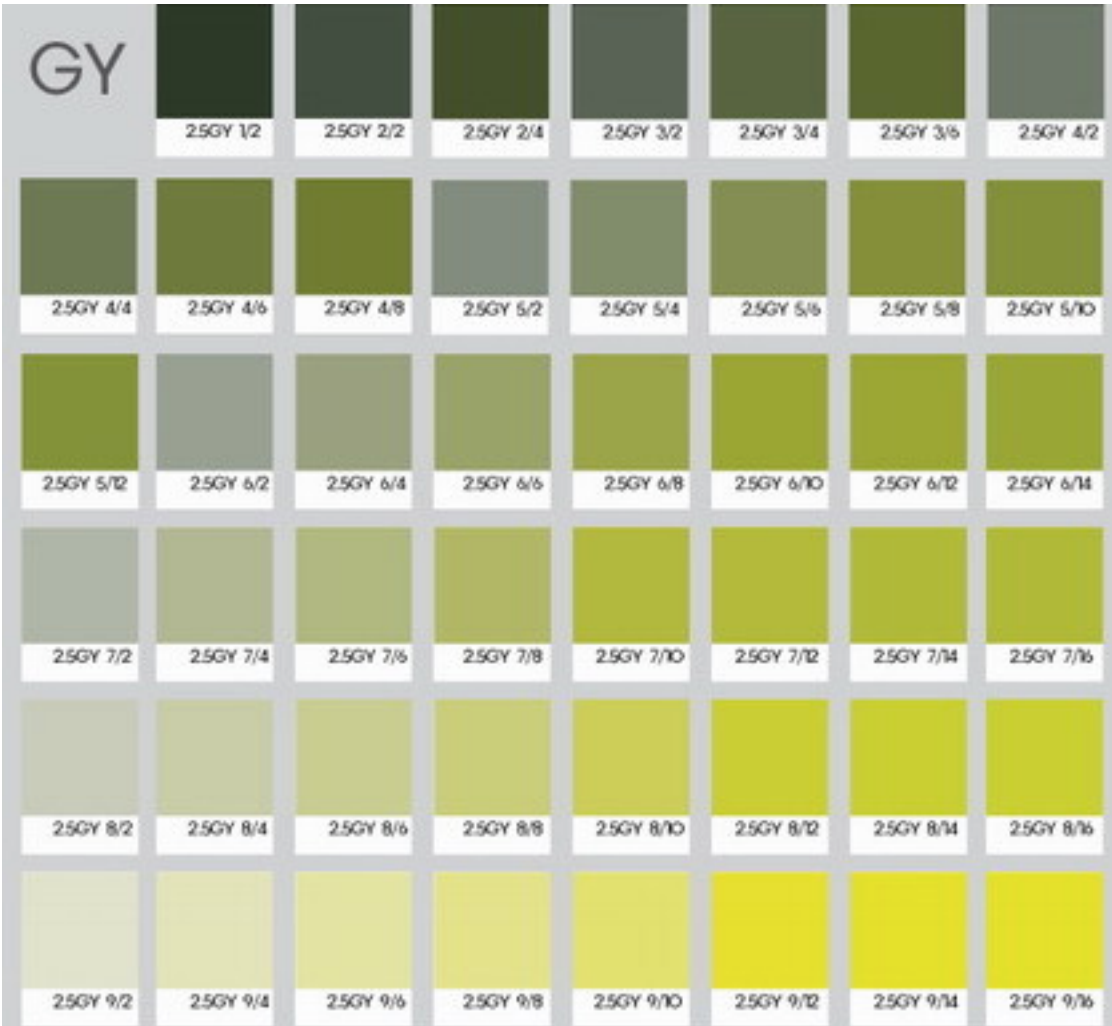

Appendix_. Munsell color chart for green-yellow hue.