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Ornamental landscapes require considerable amounts of inputs, including but not limited to irrigation, mowing or pruning, fertilization, and pest management. However, school systems have limited budgets, which reduce their access to resources and labor hours. Therefore, the objective of this project is to identify ground covers that can compete with weeds and maintain aesthetic quality while under minimal maintenance. To explore this objective, a field experiment was initiated in May 2015 at Corvallis, OR. Experimental design was a randomized complete block design with 4 replications. Factors include year (2015 and 2016) and ground cover taxa. Taxa included 3 turfgrasses (*Festuca rubra L. ssp rubra* 'Chantilly', *Festuca rubra L. spp. commutata* 'Longfellow II', *Agrostis tenuis* Sibth 'Puritan') and 7 forb or shrub plants (*Vinca minor* 'Illumination', *Cotoneaster dammeri* 'Coral Beauty', *Euonymus fortunei* 'Kawensis', *Juniperus horizontalis* 'Blue Chip', *Herniaria glabra* 'Green Carpet', *Sedum spurium* 'Tri-Color, and *Ceanothus glorious* 'Point Reyes'), which were selected using a school system stakeholder group. All plots received daily irrigation for the first 4 months and subsequently discontinued in September 2015. Plots are weeded and fertilized (4.88 g nitrogen m^{-2}) once annually. Results determined that *A. tenuis* had the highest plant

cover (68.1%), followed by *F. Rubra ‘Chantilly’* (68.1%) and *F. Rubra ‘Longfellow’* (66%), then *S. spurium* (24%) and *J. horizontalis* (22.6%). The remaining ground covers all provided less than 7% plant cover. A strong inverse correlation between plant ground cover and weed ground cover was identified in both years (R^2= 0.978, R^2= 0.948).

Low Maintenance Strategies and Challenges within Oregon School Landscapes

by

Micah A. Gould

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APPROVED:

Major Professor, representing Horticulture

Head of the Department of Horticulture

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Micah A. Gould, Author

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Introduction

A primary tactic in preventing weeds from establishing is to select a plant that develops a dense canopy. Plant competition has been seen to correlate strongly to early light interception, thus limiting weed establishment (Kruidhof et al., 2008; Fisk et al., 2000). With plant competition theoretically doing most of the work against weeds, depletion of broadleaf weed seeds in the soil seed bank over time becomes much easier by managing weed populations at low densities, rather than high (Buhler, 1999). Traditionally, ground covers are used to improve long term soil conditions, elevate crop yields, or reduce weed populations (Deguchi et al., 2007; Teasdale, 1996; Teasdale et al., 2007). With regard to successful weed reduction, commonly used living mulches in agriculture include clover species, annual ryegrass, hairy vetch, and alfalfa species (Ateh and Doll, 1996; Hiltbrunner et al., 2007; Teasdale and Daughtry, 1993; Huarte and Arnold, 2003). Most research regarding living mulches includes application in agricultural settings, and is rarely done in the urban landscape. Scientific research has been conducted on ornamental ground covers and their effects on weeds, but they are typically observed in benign environments (Eom et al., 2005; Foo et al., 2011).

The objective of this project was to quantify the effects of turf and ornamental ground covers on the incidence of weeds and to evaluate ground cover visual quality in a low input environment for possible applications in Oregon Public School landscapes.

Chapter 1

Literature Review

Introduction

Weeds often have biological attributes that allow them to grow in various microclimates throughout a landscape which is unfavorable to turfgrass and ornamental landscape plants (Turgeon, 2012). Weeds decrease crop yield in agricultural systems (Malicki and Berbeciova, 1986); however, within the urban landscape weeds decrease aesthetics (Benvenuti, 2004; Caceres et al., 2010; Masin et al., 2006), affect property values (Crompton, 2001; Zhang and Boyle, 2010), and compromise athletic field playing conditions and safety (Brosnan et al., 2014; Masin et al., 2006). By ensuring the removal of weeds, or at least limiting their numbers, the quality of these urban environmental services can be preserved.

When plants are well-adapted to an environment, or perform exceptionally they are less prone to weed invasion (Edwards et al., 2000; Kooyers and Olsen, 2012). Therefore, plant selection is a critical component to designing an urban landscape that is resistant to weed encroachment. After favorable plants are installed, focus can then be put on healthy management using cultural practices to prevent weeds like: mowing (Aldrich et al., 1972; Beck and Sebastian, 2000; Bourdot, 2016; Graglia et al., 2006), fertilization (Barker and Lubell, 2012; Edwards et al., 2000; Ervin et al., 2017), irrigation (Beck and Sebastian, 2000; Garcia et al., 2010; Reicher and Gaussoin, 2010), and mulching (Cahill et al., 2005;Cregg and Schutzki, 2009; Stinson et al., 1990).

While preventative weed management would be ideal (Hasty et al., 2004), it is sometimes not possible due to budget and labor constraints within large scale municipalities like Oregon public schools (Filardo et al., 2006). Due to the costs related in preventative weed management, herbicides are also the most cost effective method for the removal of weeds. Challenges arise for managers of public school landscapes within the state of Oregon in the selection and application of herbicides on school property. First, they face herbicide use restrictions imposed through state legislature to ensure legitimate student safety concerns, and are limited to the use of “low-impact” pesticides (Oregon Legislative Assembly, 2009; IPPC, 2014). Additionally, once an herbicide is selected, the timing of the application is often done based on the presence of children, mostly limiting applications to the summer when school is out of session. These herbicide applications in the summer may have limited effectiveness in weed control due to temperature and humidity levels (Morton and Harvey, 1994), further restricting the schools in successful and cost effective weed removal options.

The following literature review will highlight a handful of problematic weeds within the Oregon municipal landscape. Weed history, life cycle, specific environmental conditions, preventative control methods and herbicide management of each weed will be presented. After these weeds and associated factors have been presented, the literature review will transition into a discussion of favorable plant selection. Similar to the problematic weed section, a handful of favorable landscape plants within the municipal landscape will be reviewed. History, life cycle, specific environmental conditions and management practices of each ornamental plant will be presented. Finally, this literature review will focus on some of the challenges in municipal weed management, possible future water use restrictions, and state statute related to herbicide use on school property.

Common Weeds within the Urban Landscape

Annual bluegrass

History

Annual bluegrass *(Poa Annua L.)* most likely originated from *Poa infirma* and *Poa supina* by producing viable seed through crossing (Tutin, 1957). Cytology research by Koshy in 1968 suggested there may have been another species crossed, or genetic modification happened over time. Tutin (1957) believed the cross and subsequent germination of annual bluegrass happened on the northern shore of the Mediterranean around 10,000 B.C. Regardless of origin, the hardy turfgrass now inhabits much of the planet. The turf has even made it to Antactica, establishing long-term populations thanks to the continents cool summers (Pertierra et al., 2017).

Life Cycle

Currently researchers classify annual bluegrass into two varieties; *P. annua* var. *annua* and the perennial type *P. annua* var. *reptans*. The annual form puts less effort into vegetative growth and more into flowering (greater seed producing), whereas perennial forms maintain vegetative growth and minimize flowering to certain periods of the year (Lush, 1989). Similar data backs up these differences in growth. When McElroy et al. (2002) compared seedling and reproductive traits between various annual bluegrass ecotypes, they found the *P. annua* var. *reptans* variety had smaller flag leaves (21 vs. 26 mm), fewer panicles (46 vs. 128 per plant), and over 25% better seed germination than *P. annua* var. *annua*. While both are stoloniferous, Gibeault (1971) found that perennial plants had significantly more secondary tillers than that of annuals, which suggests the perennial types are putting more energy into long term survival, instead of succumbing to environmental stress as fast as the annual type. It has also been observed that the perennial types exhibit significant clonal regrowth at the end of the typical annual life cycle in early June (McElroy et. al, 2002).

A key component to annual bluegrass survival is its seed viability and self-compatibility. According to Warwick (1979) the pollen fertility of annual bluegrass is 82-99% and seed set is 86-98%. Its seed bank doesn't die off immediately either, 24% of seeds in uncultivated soil have been seen to remain viable for 6 years after seed drop and burial (Roberts and Feast, 1973).

Conducive Environments

Annual bluegrass can be found in many environments as previously stated, but generally flourishes in temperate regions around the world (Johnson and White, 1998). The plant prefers moderate temperatures, as it performs poorly under heat or cold stress. The plant does however require some cold weather to ensure proper germination and later inflorescence development. Johnson and White (1997) found *P. annua* var. *reptans* vernalized properly after 10-12 weeks at 4° Celsius(C) and 8° C, but not at 12° C. Once the seed is vernalized to an acceptable degree, germination occurs when environmental conditions are met. Maximum germination has been observed at day temperatures of 19° C and night temperatures of 10° C. Once temperatures rise to daily averages of 39° C and night averages of 29° C germination dropped dramatically to about 20% (McElroy et al., 2004).

Annual bluegrass is a photosynthetically efficient species so it will grow fine in shade or full sun. It may appear that annual bluegrass prefers growing in shade, as it often is seen doing very well in this microclimate. It is because the turfgrass is so efficient at capturing light and photosynthesizing that it out-competes other turf species in shade, like creeping bentgrass (*Agrostis stolonifera* L.) (Stiegler et al., 2003).

Control

Strategic use of pre-emergent herbicides will help reduce or contain annual bluegrass populations. Some of these herbicide common chemical names include: dithiopyr, prodiamine, benefin, oryzalin, pendimethalin, trifluralin, and many others. It should be noted that of these chemicals, pendimethalin (turf only) and trifluralin (gardens and beds) have specific applications (UCIPM, 2012). Typical application timings for established lawns in the Pacific Northwest would include early fall and another in November or March (Reicher et al., 2006) to inhibit common germination cycles of the weed. Due to the indiscriminating nature of control in regards to establishment from seed, be wary of timing for pre-emergent herbicide application. Another method, also detailed by Reicher and Gaussoin (2010) involves control by letting the turfgrass stand go dormant through the summer by shutting irrigation off, irrigating once dormant to bring back the desired turf species, then applying a pre-emergent herbicide as soon as possible to stop annual bluegrass germination.

Some non-selective, post-emergent herbicide products capable of providing control of annual bluegrass include diquat, glyphosate, and nonanoic acid, but should be limited to use in landscape beds. If applied in a lawn, the non-selective nature of these products will kill the turfgrass. However, when applied in landscape beds these products can be applied to undesirable weeds, with care to not spray desirable landscape plants as they could be damaged or killed as well. The use of dithiopyr (pre-emergent) and glyphosate (post-emergent) is often used in combination for landscape and garden use.

For further control, mulch beds with lightweight material to block out light and enable effortless hand pulling or hoeing (Davenport and Williamson, 2017).

Effective post-emergent control of annual bluegrass varies by product, climactic conditions, and timing. When applied on mature annual bluegrass ethofumesate and bispyribac-sodium exhibit somewhat effective control (Reicher and Gaussoin, 2010), but bispyribac-sodium is limited to use on golf courses and sod farms according to its label, making ethofumesate one of the more popular options for professional herbicide applicators. Ethofumesate should be applied 2-3 times to provide control, and in some cases even offers some pre-emergent activity. This product, like many others, can be highly variable (McCullough, 2016). Other products that tend to control recently established annual bluegrass include foramsulfuron, pronamide, sulfosulfuron, and trifloxysulfuron, but scouting becomes is important to ensure the plants are still in the juvenile or early growth stage when using these herbicides.

Alternative products have also been used in the attempt to control annual bluegrass. The elemental products magnesium (Mg) and iron sulfate (FeSo4) were studied by Stiegler et al (2003) to determine if a foliar application of these products could selectively reduce *P. annua* populations within creeping bentgrass putting greens. They found the products to have no effect on the annual bluegrass populations in full sun; however, in shade these products increased annual bluegrass populations. Research conducted by Ervin et al (2017) evaluated the use of Fe in combination with paclobutrazol and found that iron sulfate, regardless of the rate, decreased annual bluegrass populations to 21%, paclobutrazol reduced annual bluegrass populations to 5%, and interactions between iron sulfate and paclobutrazol were not significant. This research also found that *P. annua* populations within the control plots decreased by 8% possibly due to biweekly ammonium sulfate fertilizations.

In Japan, the chemical pyribenzoxim was evaluated for herbicidal activity and was found to selectively control many weeds; most notably large crabgrass and annual bluegrass in bentgrass stand, but ended up having trouble making it through the United State's EPA registration (Suk-Jin et al., 2006), but the product is not registered in the United States, and is traditionally used in rice. This product follows closely with methiozolin, in that it was also a product used in Japanese rice crops that attempted to become registered in the United States. The product has been issued across the country via experimental use permits, but concerns with its soil mobility and sorption (Flessner et al., 2015) have continually delayed and slowed its registration process.

White clover

History

White clover *(Trifolium repens* L.*)* is mostly used as a forage crop for grazing by animals, usually in combination with perennial ryegrass (*Lolium perenne* L.) to increase forage mass and durability of crops (Evans and Williams, 1987). The flowers of white clover are also an important provider of nectar and pollen for bee survival (Stubbendieck et al., 1989). Once boiled, clover [white and red (*Trifolium pratense* L.)] can even be consumed by humans, and is actually high in proteins and carbohydrates (Gibson and Cope, 1985).

Clover is a leguminous plant, being in the Fabaceae family, and they are known to have nitrogen fixing abilities. White clover's roots form a symbiotic relationship with a nitrogen fixing bacteria by creating an anaerobic environment that the bacteria can survive within (Giller et al., 1989). Clover can be incorporated into turf settings to increase the supply of nutrients via the soil food web while keeping the benefits grass roots have on soil structure (Van Eekeren et al., 2009). Sincik and Acikog (2007) found that white clover transfers 4.2 to 13.7% of its annually fixed N to coexisting turfgrass depending on the species. Total N fixed by the clover in the study ranged from 24.6, 30.7, and 33.8 g m^{-2} $year^{-1}$ in perennial ryegrass, Kentucky bluegrass, and creeping bentgrass, respectively. Similar to these findings, Lesuffleur et al (2013) found that perennial ryegrass took up 4 percent of N deposited by white clover root exudation.

White clover is native to Eurasia (Kooyers and Olsen, 2014), but has spread and naturalized throughout the world, including much of the United States. White clover is widespread throughout the Pacific Northwest, mainly west of the Cascade Mountain Range, and sometimes in irrigated soils east of the Cascades. This perennial has become one of the most dispersed legumes in the world (USDA NRCS, 2002). This might be explained by a study that analyzed the genes of introduced white clover species in the Central United States which were found to have rapidly adaptive evolutionary traits (Kooyers and Olsen, 2012).

Life Cycle

White clover is an easy plant to distinguish in the landscape. *Trifolium repens* means three-leaf-creeping in Latin. The solons of white clover are long-stemmed and usually contain three leaflets, but leaves containing more than 3 leaflets have been observed; due to genetic mutations (USDA NRCS, 2002). While some cultivars can produce taproots in the early life stages (Aldrich et al., 1972; Elgersma and Schlepers, 2003), stoloniferous growth is the main physical structure used for survival. The stolons simply root at the nodes when they come into contact with soil in the fall, essential for overwintering survival and spring growth (Elgersma and Schlepers, 2003). White clover typically flowers from May through July (Voth et al., 1983). The seeds typically go dormant over the winter and germinate in the spring; however some seed coats are permeable which bypasses the physical form of dormancy, leading to cases of fall germination from the current year's seed production (D'hondt et al., 2010).

Conducive Environments

White clover grows well in temperate regions preferring cool, moist conditions, (Ballizany et al., 2012). This plant is negatively affected by hot, dry summers, but in many cases is seen growing throughout the summer in areas that are provided irrigation. In the humid subtropical climate of Uruguay, white clover declined in summers without irrigation, while irrigated areas produced a good stand and yield (Garcia et al., 2010). Garcia et al also found that during under irrigated conditions profuse seedling emergence was observed, but with only a 1% survival rate. Increasing white clover drought stress though cultural practices and selective breeding is being heavily researched to improve forage yield.

Control

One cultural control for white clover might involve taking control of the plant's highly variable growth traits. For instance varieties like 'Ladino' and 'Regal' have exceptionally long stems (Hall, 1993), whereas other cultivars grow very close to the ground and are unaffected by lower mowing heights. Aldrich et al. (1972) suggest that frequent mowing at a lower height can reduce clover populations within turfgrass, while higher, less frequent mowing will favor clover. This management type would be restricted to turfgrass areas that are easily mowed, unlike landscape beds and unique areas like playgrounds.

Clover can be a hard to kill weed, but in some cases of extended periods of drought and high temperatures white clover can dissipate, like turfgrass (Gibson and Cope, 1985). In a greenhouse pot study comparing white clover and perennial ryegrass, individually and combined, soil moisture effects were more pronounced in the clover than in the ryegrass (Chen et al., 2007). If clover is more susceptible to drought than perennial ryegrass, then not irrigating fields that don't see much traffic in the summer might be an option to keep clover populations down within perennial ryegrass fields. It could be even more beneficial to seed fescues to compete with white clover, as fine fescues have been observed to be even more drought tolerant than perennial ryegrass (Aronson et al., 1987).

For exceptional, selective white clover control in cool-season turfgrass use systemic herbicides containing triclopyr (Neal, 1990). Neal also showed dicamba, clopyralid, and chlorflurenol to provide good control of clover .Using a product that contains combinations of the mentioned active ingredients is typically a strategy used to garner effective control. A non-selective herbicide like glyphosate or diquat might be an option for locations like mulched playgrounds landscape beds, or parking lots.

Large crabgrass

History

Large crabgrass (*Digitaria sanguinalis* L.) is a very common and unsightly weed that covers many tropical and temperate regions (Mitich, 1988). This warm season, summer annual has populated a large area through massive seed production (nearly 150,000 seeds per mature plant), but has been observed to have germination rates as low as 1 percent (Masin et al., 2006). Once being cultivated for grain, which was used to make flour, crabgrass species were intentionally sown into fields (Mitich, 1988).

Life Cycle

As a summer annual, large crabgrass typically germinates in late spring to early summer and has been observed to germinate 2-3 days after planting at 30 and 35°C and 9-10 days at 15°C (King and Oliver, 1994). Masin et al. (2006) observed germination in the fall likely due to summer precipitation in Legnaro, Padova, Italy where the research was conducted. The seeds can also germinate at a variety of depths within the soil, with the deepest being 8 cm in a greenhouse study by Hoyle et al. (2013). While this weed dissipates going into the cooler and darker winter months, the plant will return in turfgrass areas that are maintained at low levels the following year and continue its invasion.

Conducive Environments

Being a C-4 plant, crabgrass is able to thrive in warm, dry, and even salinized habitats (Sage and Stata, 2015). This attribute causes problems during hot summers in the Pacific Northwest where cool season turfgrasses can’t out-compete crabgrass growth. In a study where southern Californian urban lawns were subjected to increased temperature and fertilizer applications, large crabgrass was able to outcompete the traditional tall fescue lawn, producing significantly more above ground biomass (Bijoor et al., 2008).

Control

Within agriculture, the weed is a host for troublesome diseases and pests. In the southern United States, the fungal pathogen *Rhizoctonia solani* can be found within large crabgrass contaminating soybean (*Glycine max* L.) fields (Black, 1995). *Pythium* species associated with pythium root rot can be found within crabgrass contaminated sugarcane (*Saccharum officinarum* L.) fields (Dissanayake et al., 1997). They can also harbor *Pratylenchus neglectus*, a nematode, which infects potato, alfalfa, and mint (Smiley et al., 2014). In horticulture, crabgrass fills voids in landscape beds and turf, just as it would in an agricultural setting. Unfortunately, landscape beds don't benefit from seasonal tilling which discourages large crabgrass in agriculture (Aldrich, 1984).

In sports turf situations, large crabgrass can be dangerous to an athlete's health, as well as being aesthetically detrimental. When the plant is healthy, it can disrupt the uniformity of a turf stand simply by its different shades of green (Masin et al., 2006). In a traffic study comparing monostands of large crabgrass and white clover to hybrid bermudagrass, the crabgrass and clover lost their green cover about 12 times faster than the bermudagrass. The surface hardness of the crabgrass and clover plots was also 48% and 52% higher than the bermudagrass plots (Brosnan et al., 2014). Surface hardness is one of the primary factors involved in surface-related injuries in sports (Nigg and Yeadon, 1987).

The best way to reduce crabgrass germination without use of herbicides is to have dense turf (Hanson and Juska, 1964). This theory can be applied to landscape beds as well by increasing plant canopy density to restrict sun from reaching the soil surface. For lawns, competition can be improved by raising the mowing height and making timely fertilizer applications to purposely benefit the turfgrass and not crabgrass. Simply raising the mowing height from 3.8 to 7.6 cm can reduce crabgrass populations by 95 percent (Calhoun and MSU, n.d.). In the opposite situation, when reducing the mowing height from 6 cm to 3.5 cm Debels (2012) found crabgrass populations to increase by 74%, and common dandelion (*Taraxacum officinale* WEB ex WIGG.) by 32%.

A wide variety of selective and nonselective herbicides have been evaluated for use on large crabgrass in turfgrass and agricultural settings. Aulakh et al. (2015) found that combinations of pre-emergent herbicide (pendimethalin) and post-emergent herbicides (paraquat and bentazon) could not control large crabgrass in their study. Only when the pre-emergent herbicide S-metolachlor was added to the mixture was large crabgrass control achieved. In pumpkin fields, Kammler et al. (2008) achieved 89% control of crabgrass 28 days after post-emergent treatment of clethodim and a nonionic surfactant was applied to weeds that had already emerged (2008). Clethodim wouldn't be useful in turfgrass though because the chemical kills many types of grasses. The active ingredient glyphosate can be carefully used to achieve nearly 100 percent control (Gimenez et al., 1998), but repeated use of chemicals should be restricted. Crabgrass has been seen to be Glufosinate-resistant, metabolizing up to 70 percent of the chemical 72 hours after treatment in a greenhouse study (Everman et al., 2009). Use of non-selective herbicides, like glyphosate, within turfgrass would kill the surround turfgrass as well as the weed. A study by Street and Stewart (1997) found combined applications of fenoxaprop, 2,4-D, pendimethalin, MSMA, and quinclorac on established Kentucky bluegrass (*Poa pratensis* L.) to have good control of crabgrass. In New Jersey, pre-emergent crabgrass control of up to 80% was achieved with siduron in creeping bentgrass, and post-emergent control of up to nearly 100% and 80% with the use of quinclorac, in two separate years (Hart et al., 2004). This research points out that when attempting post-emergent control of crabgrass with selective products like quinclorac applications must be done early in the crabgrass life cycle, before plants exceeds the three leaves to one tiller stage.

Canada thistle

History

Canada thistle (*Cirsium arvense* L. *Scop.*) inhabits much of North America, with exception in some southern states. Within the greater Pacific Northwest, every state within the USA and Canadian province considers Canada thistle a noxious weed (USDA NRCS, 2017). This pest is relatively new to North America, with its introduction coinciding with the arrival of Western European settlers in the sixteenth century (Nuzzo, 1997). Populations were relatively minimal until the weed was brought over from Eastern Europe during the start up of the agricultural boom of the late nineteenth century in contaminated seed lots (Guggisberg et al., 2012).

Life Cycle

Much of the survival for this weed is attributed to the plant's vigorous rhizomes, but the plant is also a relatively prolific seed producer. Rutledge and McLendon (1998) determined that on average Canada thistle plants produce 1,500 seeds, which usually remain viable up to 3 years in the seed bank. Research conducted by Ross and Lembi (1999) determined that seed may remain viable for up to 20 years. Due to the rhizomatous growth habit of this weed, grounds managers may often find a cluster of Canada thistle with a system of interconnected rosettes. Canada thistle roots also sink deep into the soil depleting nutrients which reduces crop yield and landscape vigor (Malicki and Berbeciova, 1986). The roots also contain nodes that often begin new plants when the mother plant is mechanically weeded (Brandsaeter et al., 2010).

Conducive Environments

Canada thistle is a successful weed, in that it can survive in many climates. In North America alone the weed holds the noxious designation in 46 of the 50 states (USDA NRCS, 2017). A trial conducted by Liew et al. (2012) evaluated Canada thistle's sprouting capacity when exposed to combinations of temperatures (ranging from 6 to 21°C) and photoperiods (8 to 18 hours) and found that neither factor produced significant differences. This research also found that sow thistle (*Sonchus arvensis*), a plant similar to Canada thistle, germination was heavily dependent on photoperiod. In an agricultural setting, 16 Canada thistle plants per m^{-2} can reduce yield of Faba bean (*Vicia faba* L.) by 8-12% (Kalburtji and Mamolos, 2001). Diligent control of Canada thistle is warranted as its range of growth impacts crops, landscapes, and crowds out native species that may be vital to our ecosystems (Stachion and Zimdahl, 1980).

Cultural and Mechanical Control

Most methods for long term control of C. arvense involve repetitive, well-planned stressing of the root system through killing or removing above-ground plant material, or fragmentation of the root system. Soil solarization has been shown to control Canada thistle very well (Candido et al., 2011). In the same study, Candido et al observed subsequent significant increases in lettuce yields. Thomsen et al. (2001) found the use of green manure combined with tilling was able to reduce Canada thistle by 95 to 100% consistently when roots where fragmented to 5 cm in length and buried 15 cm in the soil. In research conducted by Pywell et al (2010) herbicide wiping was the most effective short term control measure, but grazing was better for long-term control of C. arvense, due to the herbicide plots regaining populations over time (Pywell et al., 2010). These findings would suggest it is important to continue attacking the plant as it may require multiple years to completely control depending on severity and levels of success year to year.

Mowing has often been shown to reduce Canada thistle populations. In a pastoral setting, mowing at least twice per year (mid-spring and mid-summer) significantly reduced Canada thistle populations in a study by Bourdot et al (2016). This research also found that Canada thistle was controlled when perennial ryegrass (*Lolium perenne* L.) was maintained between 2 and 6 cm with regular mowing. When the mowing height within this research was increased to 10 -15 cm Canada thistle was able to persist within the perennial ryegrass, but when the grass was not mowed Canada thistle did not persist. In a different study, mowing barley at 10 cm early in the year controlled Canada thistle to acceptable levels, and was speculated to be the reason for increased crop yield the subsequent year (Graglia et al., 2006). Work conducted by Beck and Sebastian (2000) showed mowing 3 times a year for 2 years in Colorado pastures reduced Canada thistle by 85% in irrigated sites, but not un-irrigated sites. Most literature suggests when mowing at higher cutting heights, some reduction of C. arvense is possible and warrants being added to management plans for the control of the weed, but as this collection of research has shown site specific conditions may influence results.

Another method for depleting the weed's below ground resources is to establish and maintain competitive plants that have similar rooting and uptake characteristics. For instance, Norland et al. (2013) found that native forb-type plants that directly compete with the thistle significantly reduced the weed in multiple locations. A study by Edwards et al (2000) showed simply fertilizing with lime and nitrogen on acidic grassland can significantly reduce Canada thistle shoot density and abundance (2000). Wilson and Kachman (1999) determined that plant competition generated by hybrid wheatgrass, intermediate wheatgrass, Russian wildrye, tall fescue, and western wheatgrass reduced Canada thistle populations by 85, 74, 76, 78, and 66%, respectively. Installing competitive plants to aid in a Canada thistle control could be a beneficial method.

Chemical Control

Fall applications of systemic, broadleaf-selective herbicides targeting underground reproductive structures are more effective on Canada thistle in the rosette stage compared to the bud stage, because during the rosette stage the plant is sending nutrients to the root regions for storage (Armel et al., 2005). A study that compared applications of glyphosate at the bud stage to the rosette stage found Canada thistle control to be 35% and 72%, respectively (Hunter, 1996). Beck and Sebastian (2000) also found that systemic chemicals providing better control than contact herbicides. Fall herbicide applications have been show to provide control ranging from 37 to 100% (Beck and Sebastian, 2000). Enloe et al (2007) found that using the most effective herbicide, which was aminopyralid in this instance, was more important that application timing as long as Canada thistle is in an early growth stage. Disregarding which season is best to spray Canada thistle; it should be noted that period of excessive heat will impede plant growth substantially decreasing herbicide uptake, metabolism and effectiveness (Haderlie et al., 1991).

Effectiveness of herbicide applications on Canada thistle can vary depending on the chemicals used and characteristics of the locations being sprayed, but generally there are effective products on the market. Beck and Sebastian (2000) found that Canada thistle in irrigated farm land could be control well with picloram, chlorsulfuron, and dicamba, while in dry land farming picloram was the only herbicide that provided acceptable control of Canada thistle. When comparing herbicide effectiveness over time, at least 78% control was achieved 2 months after individual spring applications of clopyralid, clopyralid + triclopyr, or picloram. One year later control dipped to less than 60% for all treatments (Travnicek et al., 2005). Enloe et al (2007) found aminopyralid, picloram, picloram + 2,4-D and clopyralid across 10 locations in the Great Plains to be effective at controlling Canada thistle. While a number of products have been shown to be effective on Canada thistle herbicide applications targeting the plant's roots and rhizomes will provide the best control.

Management Concerns Regarding Landscapes

Mulching Around Ground Covers

Generally speaking, plants whose apical meristem, such as turfgrass, or vegetative canopy reside near the soil surface will not be appropriate for mulch application because the material could smother the plant. Plants mentioned that would not respond well to mulch application include: colonial bentgrass, chewings fescue, creeping red fescue, dwarf periwinkle, caucasian stonecrop, winter creeper, and green carpet. This section will mostly focus on plants that can be easily mulched (such as creeping juniper, prostrate ceanothus, and bearberry cotoneaster).

There are many types of landscape mulches available, and they can be divided into organic, mineral, and synthetic materials. Organic mulch options often include, but are not limited to, bark mulch, pine needles, sawdust, cardboard, manure, grass clippings, leaves, and wood chips (Chalker-Scott, 2007). When selecting organic mulches, the primary factors to consider are cost and aesthetics. In a study comparing organic mulches three of the four materials improved the health of various landscape plants when compared to a control of no mulch + weed control (Cregg and Schutzki, 2009). The research conducted by Creeg and Schutzki (2009) found that shredded cypress was the only material in their study that did not improve landscape plant health; compared to pine nuggets and pine straw. There are also mineral and synthetic options including pea gravel, crushed rock, stone, rubber pieces, plastic pellets, and plastic sheets (Chalker-Scott, 2007). Mineral mulches tend to be used in more arid regions, like southern California, Nevada, and Arizona, but can be less effective at moderating heat gain and soil water loss than traditional organic materials used in the area (Singer and Martin, 2008). While hot areas such as these might disregard the use of organics due to fire-starting concerns, a study by Steward et al. (2003) compared the ignition of 13 mulches and found there to be organic and synthetic mulches that were both hard and easy to ignite when exposed to a torch.

Some may argue mulching is generally performed to increase aesthetics, but reducing weeds is one of the most beneficial effects of mulch application in landscape management and agricultural applications. Research conducted by Stinson et al. (1990) compared 15 different mulches and found that they all significantly reduced weed populations in comparison to bare soil (1990). It was found that the common way these mulches reduced weed populations was by preventing seed germination by blocking light with a 7.5 cm or greater layer of material (Cahill et al., 2005). When restoring landscapes from turfgrass to urban forests, mulching alone can decrease turfgrass populations, while not impeding desired plant growth (DeJong et al., 2017). Research evaluating the application of mulch to lentil crops in Stuttgart, Germany, found weed biomass and weed density was reduced by 43-51% and 29-30%, respectively (Wang et al., 2012). Research conducted on olive production also demonstrated moderate control from mulching alone when pre-emergent herbicides were not applied (Henry and Hoyle, 2015). While mulch application was found to provide weed control in these research projects, these studies did not analyze the cost effectiveness of mulch materials. In order to analyze the costs and benefits of mulching, one must consider the other services provided by mulch application.

Other effects of mulching include modification of hydrologic cycles and soil characteristics. Mulches such asrock fragments, layers of branches, and even living mulches like hedgerows can improve soil infiltration and enhancing groundwater recharge (Cerda, 2001; Tongway and Ludwig, 1996; Stroosnijder, 2009). When studying pine straw in a stand of loblolly pine (*Pinus taeda* L.), runoff increased in areas where pine straw was collected annually when compared to areas were the straw was left to accumulate for two years (Pote et al., 2004). Mulch has been shown to decrease evapotranspiration, soil water depletion, and increase water-use efficiency (Huang et al., 2005). Mulching also protects soil structure and prevents compaction by acting as a barrier from harsh weather conditions or heavy traffic (Jury and Horton, 2004; Oliveira and Merwin, 2001). However, not all mulches improve soil drainage and prevent runoff. Fine-type material for instance can limit gas exchange and water infiltration by clogging or creating a barrier between the atmosphere and soil (Stenn, 2005). Some mulch materials, such as plastics, geo-textiles, fine-textured organics, sheet mulches, and waxy coated types, can become compact or form impenetrable layers (Chalker-Scott, 2007).

Irrigation

Most of the western United States has experienced a severe drought lasting many consecutive years; while not nearly as arid as droughts from 900 to 1300 AD, it has caused concern for possibly long-term warmer temperatures (Cook et al., 2004). In fact according to paleoclimatic records, droughts during the 20th century, like within the Great Plains, are minute when compared to epic droughts that have occurred several times in the last 2000 years (Woodhouse and Overpeck, 1998). These results also predict that "droughts more severe than those of the 1930's and 1950's are likely to occur in the future."

More recently, in the last four decades there have been four droughts on record in California. Starting in 2012, the nearest drought has marked the driest three year stretch in 120 years in California. In response to these conditions California Governor Jerry Brown authorized an executive order restricting water within the urban by 25 percent

(Cousineau, 2015). The order also declared that 50 million square feet of turfgrass were to be removed, and led to the establishment of the state-wide Turf Replacement Initiative. One water district of 26 cities, which imports supplemental water from the Colorado River and Northern California, fulfilled the 50 million square feet removal completely on its own (The Metropolitan Water District of Southern C., 2015). Once the initiative concluded, a total of 170 million square feet of turfgrass was removed in Southern California alone (Metropolitan Water District of S. California, n.d.).

Luckily the United States as a whole is trending towards reducing water usage. In 2005 an estimated 408 billion gallons of water were used per day, and by 2010 that number was reduced to 355 billion. Of the 355 billion, fourteen percent of water was saline, with the rest being fresh water (Maupin et al., 2014). The Pacific Northwest can learn from the droughty conditions of its neighbors to the south by taking advantage of alternative irrigation sources, improved irrigation technologies, and incorporation of drought tolerant plants into the landscape.

Irrigation Source: Effluent Water

A promising alternative to potable irrigation water involves the use of recycled wastewater, often called effluent. Effluent irrigation is most valuable in areas that receive low and sporadic rainfall, but may become increasingly popular with climate change effects and spreading water conservation efforts (Derry, 2001). Golf courses and urban landscapes have commonly been adopting the use of effluent water to irrigate plants in the United States, especially in arid and semi-arid regions (Qian and Mecham, 2005). Using effluent water for landscape irrigation in the Pacific Northwest could save potable water for more important uses.

There are three common levels of treatment that most treatment facilities provide: primary, secondary, and tertiary stages. Primary treatment involves eliminating some of the solids and sediments and requires further treatment to achieve potable water quality (Gehr et al., 2003). In the secondary treatment stage microorganisms (bacteria, protozoa, and microalgae) break down the remaining organic matter within the water (Cho et al., 2011). Tertiary treatment typically involves a more sophisticated version of secondary treatment to remove contaminants like fecal coliforms, and may consist of contact filters like sand (99% reduction), chemical (39% reduction), and biological-chemical (71% reduction) (Koivunen et al., 2003).

Although many contaminants can effectively be removed in modern treatment facilities, pharmaceuticals and personal care products (PPCPs) can slip by said filters and may pose a threat to human health. For instance, research conducted by Jelic et al. (2011) analyzed treated effluent water from 3 treatment facilities for pharmaceutical compounds and found 29 different compounds in outgoing effluent wastewater. Other studies have shown that current methods can effectively remove certain PPCPs (Boyd et al., 2003). To ensure the health of downstream organisms (plants, animals, and humans) either more efficient compound removal will have to occur, or the use of effluent will continue to be limited to specific applications. Research has determined that when applied to turfgrass PPCPs have been seen to be completely trapped within the root zone, even with above average irrigation rates (Bondarenko et al., 2012).

Depending on the quality, irrigating landscapes with effluent water can have adverse effects on the soil environment, indirectly affecting plant health. The problems the soil environments exhibit are attributed to long term exposure (accumulation) of sodium and salts carried by effluent water. Golf course fairways irrigated with effluent water resulted in an average electric conductivity (EC) of 0.84 dS m^{-1}, compared to surface water, which produced an average EC of 0.23 dS m^{-1} (Qian and Mecham, 2005). These differences equated to 187% higher EC and 481% higher sodium adsorption ratios (SAR) as the result of effluent water irrigation. After 4 or 5 years of applying effluent water the fairway soils also contained higher concentrations of sodium (Na) (200%), boron (B) (40%), and phosphorus (P) (30%), which correlate to the higher EC and SAR values. With increased SAR concentrations excess Na often replaces calcium (CA) and magnesium (Mg) on clay particles, leading to deflocculation of the soil particles and subsequently reducing soil infiltration (Halliwell et al., 2001). Increased Na and chlorine (Cl) levels also can lead to physiological drought of plants by reducing the osmotic potential (Marcum, 2005), and even nutrient deficiencies (Marschner, 1995).

Altering management practices can counteract, or at least mitigate these detrimental effects. First of all, purposeful leaching can be done to dilute or push the salt concentrations out of the root zone (Turgeon, 2012). Another method would be to supplement the effluent source with a clean irrigation source when Na and salt levels surpass an undesired threshold. Planting salt tolerant species is another option, but it would not solve issues like reduced soil infiltration from Na (Harivandi, 2011). It should be noted that salt tolerance between species can vary, turfgrass and ornamentals alike (Table 1.1; Table 1.2; Miyamoto et al., 2004). In regards to turfgrass management, when effluent irrigation is the primary source on putting greens, applying gypsum and regular sand topdressing has shown to increase water infiltration compared to wetting agents and topdressing (Chang et al., 2013).

Landscape Irrigation Reduction

The use of smart irrigation controllers is trending and will only grow with time as water becomes more valuable. California, Texas, and Florida have approved legislation to incentivize the use of the controllers, and require performance standards of various irrigation equipment (California Legislative Information, 2016; Compliance Support Division, 2009; The Florida Legislature, 2017). Most scientific studies show potential water savings of 40% to 70%, although most pilot projects result in 10% or fewer savings due to climate, project scale, effective implementation, and type of irrigation user (typically already frugal) (Dukes, 2012). Nationally, the WaterSense Program by the EPA is certifying manufactures for water efficiency, educating the public, and offering tips to consumers to reduce normal water usage by 20% (Manuel, 2008).

The use of smart irrigation controllers is a great way to ensure reductions in irrigation volume in a landscape. Types of controllers often used are ones that base irrigation needs off of calculated plant evapotranspiration (ET), rain sensors, or soil moisture sensors. When comparing three different ET based controller brands fitted with rain sensors it was found that on average the controllers applied 50% of the calculated requirement for replacing water lost during each event, an increase of 8% based off of previous research; suggesting limitations to the installed rain sensors or the controllers' internal computer that calculates ET replacement is simply set to replace a smaller percentage of water lost (Davis and Dukes, 2010). All controllers applied less irrigation than required for all seasons of the year, which suggests simply replacing old technology with modern controllers will help reduce irrigation application alone. The study also mentioned that two controller settings that impacted results were specific crop coefficients and soil types, and it was extremely important to use a rain sensor, especially when non ET based controllers are to be used. Soil moisture sensors have also been shown to reduce irrigation events from 4.5-6 events per month to as little as 2, and this reduction in application events resulted in a 65% reduction compared to homes with typical timer based controllers (Haley and Dukes, 2011). However, other factors like site specific climates likely play a larger part in the selection and adoption of controller type.

Another method to reduce water use involves installing more efficient types of irrigation systems. Subsurface drip irrigation (SDI) has often been used in landscape beds but is also applicable for turfgrass, and has used in cropping systems to reduce irrigation rates (Romero et al., 2005, Von Westarp et al., 2004, Yuan et al., 2003). SDI has the ability to directly apply irrigation to the root zone, minimizing problems such as overspray, runoff, wind drift and human exposure (Leinauer and Devitt, 2013). SDI has been seen to reduce irrigation needs by 25-55% (Lamm et al., 1995, Lamm and Trooien, 2003, Romero et al., 2005) when compared to traditional irrigation. Although SDI can have higher installation costs than traditional irrigation, it can be profitable when lasting 7-10 years (Dougherty et al., 2009, Sharmasarkar et al., 2001, O’Brien et al., 1998). In turfgrass, SDI can also be used to establish cool-season turfgrasses from seed, with the only detriment being a delay of establishment compared to sprinkler irrigated plots (Schiavon et al., 2013). Other disadvantages include emitters plugging, poor soil surface moisture, and difficulty finding and fixing leaks (Camp and Lamm, 2003).

Low Maintenance Plant Selection for Public School Landscapes

Considering the limitations facing Oregon schools, an option for improving landscapes may be selecting plant species (turf and ground covers) adapted to low input environments (DeBels et al., 2012). Oregon schools are limited by their budgets, so their environments are naturally nutrient poor as they cannot afford fertilizers. These environments can easily become infested with weeds with little to no competition in the form of desirable landscape plants, or even weed suppressive strategies like mulching. Plants that can compete and reduce weed populations while surviving such difficult environments would be suitable for landscapes seen in Oregon's public school system. Plants like these will be the next focus within the literature review. Input provided by Oregon school employees at annual school grounds trainings, organized by the OSU School IPM Program, suggests that plant height should be reduced to discourage criminals from targeting or hiding around school grounds. Excessive maintenance is required to shape plants in such a way that visibility isn't obstructed from one side of the plant to the other. By selecting plants that are more low growing, schools around the Pacific Northwest would, in a way, be safer for the attending children, and might reduce current labor hours allotted for landscape beds, freeing up time and costs for other important landscape needs.

Turfgrass

Colonial bentgrass

Making its way to Oregon most likely alongside settlers, Colonial bentgrass (*Agrostis tenuis* 'Sibth') fit in well with the surrounding mild climate west of the Cascades. With such favorable growing conditions for the turfgrass plant, various bentgrass species make up most matured climax lawns in the Pacific Northwest (Cook, 2002). It is often found in full sun locations, but has some shade tolerance (UCIPM, 2016).

Water needs are fairly average with colonial bentgrass, with similar drought tolerance as most cool season grasses, with the exception of fescues being hardier (Harivandi et al., 1984). When the plant is irrigated, DaCosta and Huang were able to conclude that acceptable turfgrass quality was achieved at 80% evapotranspiration (ET) replacement, a method of calculating irrigation applications (2006). This turfgrass has drought tolerance potential, but often exhibits drought avoidance when irrigation is not applied. As many Oregonians don't irrigate in the summer, the turf goes dormant; springing back up when regular precipitation returns in the fall (Cook, 2002).

This turf can be a relatively low fertility option for use as a lawn. Nitrogen requirements range from 49 to 146 kg N ha-1 (Bonos, 2008; Horgan, 2007), with lower nutrient ranges requiring the return of mowed clippings to produce acceptable turfgrass quality ratings. In a golf course fairway setting mowed at 2.5 cm, colonial bentgrass varieties were able to produce high percent living ground cover ratings, mostly above 90 percent over two years, but low fertility rates (49 kg N ha-1) failed to average acceptable quality ratings, whereas the high rates (146 kg N ha-1) just barely did (Horgan et al., 2007).

The most labor intensive aspect of maintaining colonial bentgrasses is mowing requirements, in terms of aesthetics. This plant has a small range of preferred mowing heights. It prefers heights no shorter than 0.95 cm (Weibel et al., 2012) and no longer than 2.5 cm; some newer cultivars up to 5.1 cm (Cook, 2002). Lower mowing heights translate to more frequent mowing events or more frequent maintenance if mowing is necessary, as to prevent scalping which can produce unacceptable turfgrass quality (McCarty et al., 2007). This grass will also develop false crowing at higher mowing heights, and can look somewhat unkempt and out of place (Brede, 2004).

In prairie settings, which lack any typical turfgrass maintenance, colonial bentgrass populations remained relatively constant to slightly increasing in size (Garrison and Stier, 2010). This study was carried out in the Upper Midwest prairies, and they concluded that non-native grasses may be poor competitors in restored prairies. However, their results might suggest that in very low maintenance situations the turfgrass can persist over time. Even if the results didn’t translate to Pacific Northwest areas, supplementing with extra seed in maintained sites may help sustain high plant densities if populations were to decline.

Fine Fescue

Fine fescues refer to fine leaved turfgrasses in the fescue genus. These plants consist of creeping red fescue, chewings fescue, hard fescue, and sheep fescue. Of these fine fescue plants chewings and creeping red fescue will be explored in more detail for possible use in Oregon school landscapes for their low input characteristics.

Chewings fescue *(Festuca rubra ssp. commutata (Thuill.) Nyman.)*, in the group of fine fescues, was bred and distributed in New Zealand by a man named George Chewings in 1887 (Turfonline, 2016). Strong creeping red fescue *(Festuca rubra* L. subsp. *rubra)* is very similar in appearance to Chewings fescue (Cook, n.d). Unlike Chewings fescue, red fescues grows less upright and spreads via rhizomes, a trait specific to this fescue (NC State University, n.d.).

What makes these fine fescues so popular is their shade tolerance, and ability to live in low fertility soils, and drought tolerance. When compared to many other cool-season turfgrasses grown in high shade environments, fine fescue quality measured among the best, with only tall fescue outperforming it (Gardner and Taylor, 2002).

In general, what makes these plants good candidates for Oregon schools is their low input requirements. Acceptable turfgrass quality can be achieved at 97.7 kg N ha-1 per year, often even lower (Fresenburg, 2016). If quality is sought with this turfgrass, turf color and quality are generally associated with increasing fertility by enhancing color and quality ratings, and increasing clipping yield when higher amounts of nitrogen are applied (Bilgili and Acikgoz, 2005).

Fine fescues are also exceptionally adapted for living amidst droughty conditions. Aronson and others found fine fescue species to maintain relatively constant leaf water potential at -400 kPa, where *Poa pratensis* and *Lolium perenne* decreased by 50 to 75% at a soil water potential of -80 kPa (1987). Overall, these plants are especially hardy and can persist in even the lowest of maintained landscapes.

Fescues can even be used as a type of ornamental by not regularly mowing, enabling the wispy-like stalk to extend and flow in the wind. These no-mow situations obtain a more naturalized landscape look, but they still require maintenance. Although the name “no-mow” suggests otherwise, these applications of fescue are usually mowed 1-2 times annually around 4-6 inches high (spring and/or fall) to remove dead vegetation, rejuvenate the plants appearance, and to control growth (UMN Extension, n.d.).

Herbaceous and Woody Ground Covers

Creeping juniper

Creeping juniper *(Juniperus horizontalis)*, one of the smallest growing juniper plants (4-12 inches tall), inhabits most of Canada and the Northern United States; located in USDA hardiness zones 3a (Jull, 2009). Unlike its larger relative western juniper, which occupies 9 million acreas, it is not nearly as invasive, if at all (Miller, 2005). It is small but creeps up to 7-8 feet in diameter, like its name suggests. Stems occasionally root when in contact with soil, further enabling the establishment of a dense ground cover. The hardy plant can inhabit rocky soils and usually is found in sand, and does not prefer wet feet (Elliot, 2013).

Apart from horticultural applications, creeping juniper has uses ranging from beverages to medicinal uses. Juniper berries are used as the “principal ingredient used for gin aromatization (Vichi et al., 2007).” More importantly creeping juniper has potential to be useful in the medical field as the “needles can be utilized as a source of both essential oil and podophyllotoxin,” an anticancer drug synthetic precursor (Cantrell, 2014). This drug has many applications in the form of a medicinal cream.

There is promise for use of this plant in Oregon, especially because it is already a feature; found in various harsh environments like parking lot and road side settings. It can handle rocky areas and tolerates hot and dry climates, and even salt stress via soil and spray (Appleton et al., 2009). Planting on slopes for soil reinforcement is also a common practice. Cotoneaster dammeri was found to have the highest root tensile strength and soil reinforcement values, but *J. horizontalis* and *Rosa canina* produced moderate results themselves (Comino and Marengo, 2010).

The plant should probably not be used solely as a nitrate runoff interceptor though, as 58-80% of slow release fertilizers were not recovered by the plant in a potted study where annual runoff was simulated as a one-time event (Rathier and Frink, 1989). With these results kept in mind, purposeful fertilizations would be more efficiently taken up by the plant if they were spread out among multiple applications, instead of one heavier fertilization. In general, this is a good practice as less fertilization is lost through the soil, and there are not excessive nutrients available for off-target plants, like weeds. Timing of these applications isn't very important either, in terms of channeling plant growth during specific times of the year. Hicklenton and Cairns found "no evidence that seasonal growth could be enhanced in either *c. dammeri* or *j. horizontalis* (1992)."

Plants within the genus Juniperus are "spreading rapidly in distribution, abundance, and dominance in arid and semiarid regions," becoming a class of drought tolerant juggernauts (Willson et al., 2008). J. horizontalis is consistent with other Juniperus plants, from establishment to being a mature plant. In fact, irrigation equal to 14% or less of reference ET can be used to establish the ground cover with no drought-related injuries (Sachs, 1991). The same study found that by providing these irrigation conditions for 2 years allowed the plant to become established, by then reducing irrigation at all without injury. As long as initial irrigation is applied, even if in small amounts, future water savings can surely be expected with this landscape ground cover.

Caucasian stonecrop

Caucasian stonecrop *(Sedum spurium)* is a low growing plant (6 inches max) and spreads by rooting at nodes that come into contact with soil (Missouri Botanical Garden, n.d.). Native to the Caucasus, this hardy sedum can survive anywhere from zones 3 to 8, sometimes even zone 9. There are a plethora of cultivars, each one bred for unique color combinations and patters (Biggs and Rhodus, n.d.). If this plant is used indoors, it should be noted that cultivars are moderately poisonous when eaten which mostly poses a threat to cats, as they are known to snack on indoor plant foliage (NCSU and A&TSU, n.d.).

S. spurium is a ground cover often used in green roofs and rock gardens. When utilized as a green roof component, it performs exceptionally well in mitigating storm water and reducing temperature. DeNardo and others found *S. spurium* to provide various benefits including: delaying the start of runoff on average by 5.7 hours, retaining 45% of storm water, delaying peak runoff by 2 hours, warming surface temperatures by 6°C in the winter, and cooling summer surface temperatures by 19°C (2005).

Besides having showy, fleshy, foliage, stonecrop is a popular landscape plant because of its ability to live in hot and dry climates. When compared to 12 other sedum species, S. *spurium* performed near the top in terms of establishment until providing absolute cover, only second to *sedum sarmentosum*, a really aggressive plant (Getter and Rowe, 2008). Another study shows S. *spurium* containing the highest drought tolerance, with *S. sarmentosum* lower on the list of 7 sedum species (Zhou and Wang, 2009). Sedum also was considered to be more drought tolerant than forbs and grasses, where the forbs and grasses tolerated drought similarly, in a green roof study (Nagase and Dunnett, 2010). Just like the media used in these green roof studies, sedum seems to prefer rougher soils like those containing sand and gravel, and flourishes with good drainage.

During winter, aesthetic components of this plant decline. It is a semi-evergreen, which retains some leaves all year round, but the bulk of them may fall off. Terminal leaves remain present in an off-colored state, whereas the remaining leaves down crown fall off, not returning until spring (Biggs and Rhodus, n.d.). This winter injury can at least be reduced with the use of fertilizers containing phosphorus and potassium for some sedum species (Clark and Zheng, 2012). While poor aesthetics for a short time can easily be tolerated, the bare soil that is uncovered poses a bigger threat, allowing for easy germination of weeds without competition. Control of weeds in a ground cover like this is limited to hand pulling and chemical spot treatment via sponge or brush. Broadcast chemical sprays shouldn’t be recommended with this ground cover, as most chemicals (selective and non-selective) would probably damage or kill the herbaceous plant.

Efforts should be put into ensuring establishment, by providing proper fertilizer applications until maturity, which tend to be guidelines of any landscape plant. Planting at different times of the year has also been shown to be significantly different for sedum species. Survival was found to be 81% in the spring, but only 23% in the fall when using sedum plugs on a green roof in East Lansing, MI (Getter and Rowe, 2007). Like many plants, higher fertility regimes generally lead to greater quality and plant mass accumulation (Barker and Lubell, 2012). The same study interestingly concluded that some sedum species experienced "melt-out," or when higher fertility regimes turned tissue brown and subsequently desiccated, in turn lowering visual quality.

In terms of irrigation, special attention to preventing over-watering should be taken. Soil that is wet for long periods of time may be detrimental to the plant's health. During dry periods, sedum should be watered about once a week at most, with minimum irrigation frequencies about once every 3 weeks, but reduced quality can be expected when stretching irrigation events this far apart (Nagase and Dunnett, 2010).

Dwarf periwinkle

Dwarf periwinkle *(Vinca minor)* is a low growing groundcover native to Europe and southern Russia and covers hardiness zones 4-8 (Missouri Botanical Garden, n.d.). The plant only gets about 6 inches off of the ground and typically spreads about 6 inches (Streich and Steinegger, 1984), but can grow up to 3 feet in diameter from a single plant (Biggs and Rhodus, n.d.). Dwarf periwinkle is suited for smothering weeds naturally, providing erosion control with its rooting stems (Missouri Botanical Garden, n.d.), and providing aesthetic components with showy flowers in spring (Klett and Wilson, 2007).

There are places throughout the US where this ground cover is invasive (Swearingen and Bargeron, 2016), but is limited to the eastern states (USDANRCS, n.d.). The plant's relative, *Vinca major* currently can be found in a handful of western states, and is often a key groundcover found in the redwood forests in California (Stone, 2009). When invading non-native forests, these ground covers have been found to change the structure of forest floor litter and soil microhabitat, as well as altering spider species diversity and evenness (Bultman and DeWitt, 2008). It is possible that V. minor could also become invasive at some point in western states. The plants growth traits not only make it a good candidate for low maintenance landscapes; they enable it to grow in many environments without the need of human inputs.

V. minor grows in sun to part shade (Streich and Steinegger, 1984), but has been seen being slow to establish in full sun conditions, but will eventually spread well (Eom et al., 2005). Poor soils are typically the location where this periwinkle is transplanted, because it tolerates these conditions (Missouri Botanical Garden, n.d.)

When planting, spacing at 12-18 inches will allow for covering large areas. This plant is arguably one of the most popular choices for groundcovers (Missouri Botanical Garden, n.d.), and when bought in bulk it can be reasonably priced. Planting should occur in the spring and could be given a complete fertilizer to improve its establishment.

V. minor requires only medium amounts of water during droughty conditions (Missouri Botanical Garden, n.d.).The plant prefers dry soil, but should be irrigated frequently during drought to maintain growth (Streich and Steinegger, 1984). On the lower spectrum, two irrigation events per month have been recommended to at least keep the plant alive (Bautista, 2000).

Difficulties and Restrictions in the Oregon Public School System

The Oregon Public School system, compared to other public school systems in the United States, is poorly funded. From 1995 to 2004 Oregon Public schools' construction expenditures per student varied from $4,000-$5,999 (the second lowest numerical range possible) while enrollment increased between 6-10% (the second highest numerical range possible) (Filardo et al., 2006). Because it has been recorded that improving school building conditions can improve students' learning experience and potential, and the fact that school facilities nationwide are underinvested in, it is inherent that landscape maintenance will be the lowest priority, monetarily, in public schools compared to other education and facilities needs. However, priorities need to be reevaluated and funding for all aspects of the education system should be more readily available as research has shown that improving the environments in and around schools increases student learning and testing scores (Earthman, 2004; Edwards, 1991).

While preventative weed management would be ideal (Hasty et al., 2004), it is sometimes not possible due to budget and labor constraints within large scale systems like Oregon public schools, as mentioned. Due to the costs related to preventative weed management, herbicides are the simplest and most cost effective method for the removal of weeds. Challenges arise for managers of public school landscapes within the state of Oregon in the selection and application of herbicides on school property.

As of 2009, the state of Oregon requires all schools (K–12 public and private) to implement integrated pest management (IPPC, 2013; Oregon Legislative Assembly, 2009). Some of the requirements of the Oregon IPM Law include the development and implementation of an IPM plan, designating an IPM Coordinator for the respective school districts, annual IPM training for the designated IPM Coordinators and school employees, and the development and use of a state accepted low-impact pesticide list (IPPC, 2014). Within this statute, low-impact pesticides are defined as those that do not contain active ingredients with the signal word “warning” or “danger,” or contain an active ingredient classified as a probable or known human carcinogen (USEPA, 2005). Similar pesticide restrictions have been developed by several states across the United States (Hurley et al., 2014), although the manner and degree to which these restrictions are enforced varies. Common restrictions include, but are not limited to, restricted spray zones, reentry requirements beyond label, and definitions of the types of products to be used in and around schools (Kowalewski et al., 2016).

These restrictions make selecting herbicides difficult enough for grounds managers, and applying them can be equally challenging. Once an herbicide is approved for use, the timing of the application is often based on the absence of children; limiting applications to the summer when school is out of session. These herbicide applications in the summer may have limited effectiveness in weed control due to temperature and humidity levels (Morton and Harvey, 1994), further restricting the schools in successful and cost effective weed removal options.

Conclusion

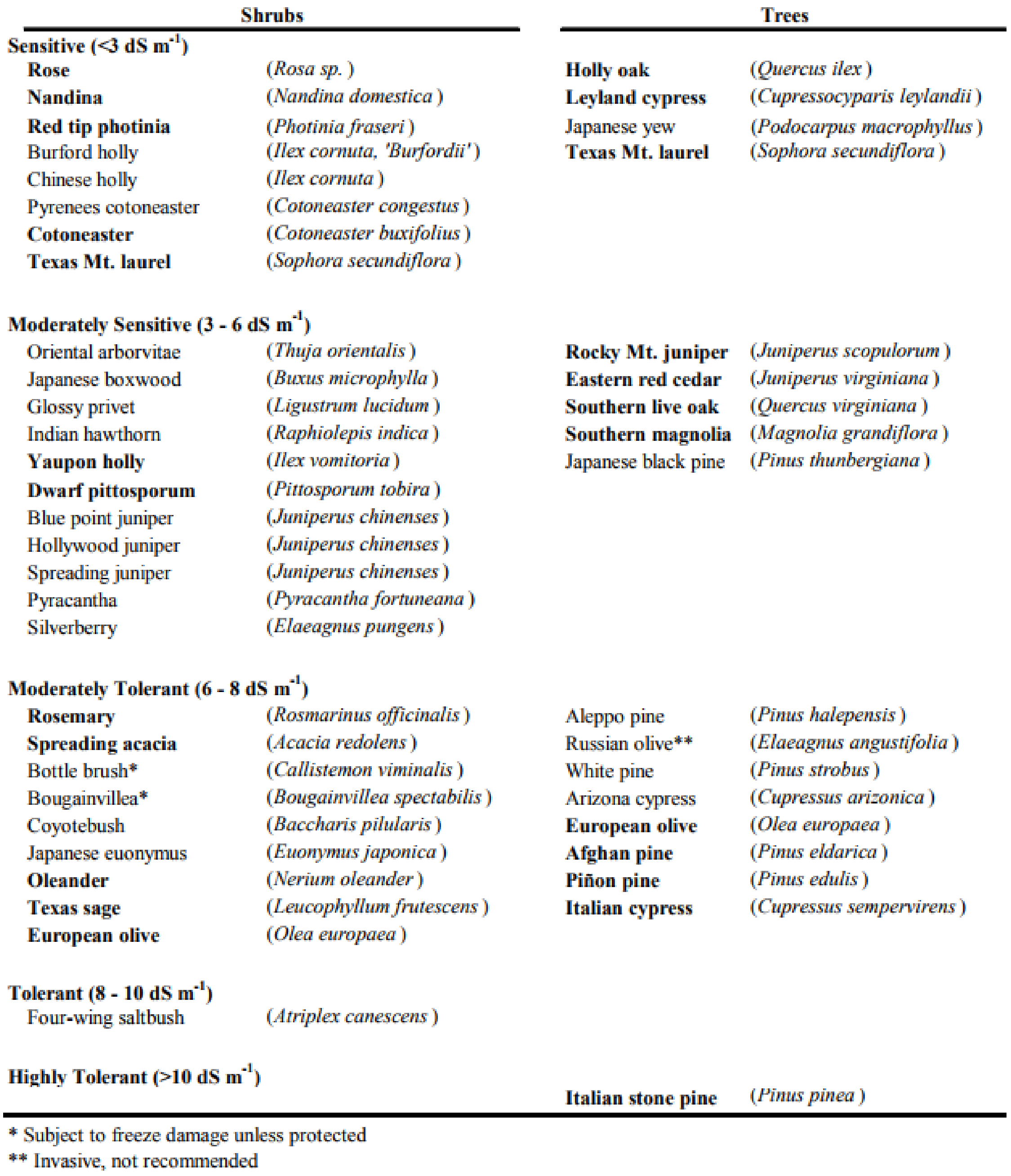
In conclusion, Oregon school grounds managers face many challenges within landscape maintenance alone, without taking into account many other tasks they are accountable for. Based on available resources, current landscape maintenance requirements are not attainable, even with lower expectations. Landscapes with such minimal inputs have led to extremely weedy environments that cannot be effectively prevented, and are limited in their curative control. It seems that some turfgrasses and ground covers may provide an alternative option to weed management in low maintenance landscapes like these. However, if budgets for Oregon school grounds managers aren’t increased and more emphasis put into IPM for landscape maintenance in the future, there may be consequences directly impacting communities’ student health, aesthetics, and the functional capacity school grounds provide.

Tables

Table 1.1 Degrees of salt tolerance for warm and cool season grass species. Reprinted from Miyamoto et al (2004) and bolded species were included in their research experiments.

Warm Season		Cool Season	
Sensitive (<3 dS m^{-1})			
Black grama	(*Bouteloua eriopoda*)	Kentucky bluegrass	(*Poa pratensis*)
		Rough bluegrass	(*Poa trivialis*)
		Colonial bentgrass	(*Agrostis capillaris*)
Moderately Sensitive (3 - 6 dS m^{-1})			
Bahiagrass	(*Paspalum notatum*)	**Plains bluegrass**	(*Poa arida*)
Blue grama	(*Bouteloua gracilis 'Alma'*)	**Big bluegrass**	(*Poa secunda*)
Buffalograss	(*Buchloe dactyloides*)	Creeping bentgrass	(*Agrostis palustris*)
Blue grama	(*Bouteloua gracilis 'Bad River'*)	Annual ryegrass	(*Lolium multiforum*)
		Intermediate wheatgrass	(*Elytrigia intermedia 'Rush'*)
Moderately Tolerant (6 - 8 dS m^{-1})			
Zoysiagrass 'Zenith'	(*Zoysia sp. hybrid*)	**Intermediate wheatgrass**	(*Elytrigia intermedia 'Topar'*)
		Streambank wheatgrass	(*Elymus lanceolatus*)
		Crested wheatgrass	(*Agropyron desertorum*)
		Red fescue	(*Festuca rubra*)
		Perennial ryegrass	(*Lolium perenne*)
Tolerant (8 - 10 dS m^{-1})			
Bermudagrass	(*Cynodon dactylon*)	**Tall fescue**	(*Festuca arundinacea*)
St. Augustinegrass	(*Stenotaphrum secundatum*)	**Wild ryegrass 'Rio'**	(*Elymus triticoides*)
Highly Tolerant (>10 dS m^{-1})			
Alkali muhly	(*Muhlenbergia asperifolia*)	**Tall wheatgrass**	(*Thinopyrum ponticum*)
Desert saltgrass	(*Distichlis spicata*)	**Fults alkaligrass**	(*Puccinellia distans*)

Table 1.2 Salt tolerances of evergreen shrubs and trees, and conifers. Reprinted from Miyamoto et al. (2004), and bolded species were included in their research experiments.



Shrubs		Trees	
Sensitive (<3 dS m^{-1})			
Rose	(*Rosa sp.*)	**Holly oak**	(*Quercus ilex*)
Nandina	(*Nandina domestica*)	**Leyland cypress**	(*Cupressocyparis leylandii*)
Red tip photinia	(*Photinia fraseri*)	Japanese yew	(*Podocarpus macrophyllus*)
Burford holly	(*Ilex cornuta, 'Burfordii'*)	**Texas Mt. laurel**	(*Sophora secundiflora*)
Chinese holly	(*Ilex cornuta*)		
Pyrenees cotoneaster	(*Cotoneaster congestus*)		
Cotoneaster	(*Cotoneaster buxifolius*)		
Texas Mt. laurel	(*Sophora secundiflora*)		
Moderately Sensitive (3 - 6 dS m^{-1})			
Oriental arborvitae	(*Thuja orientalis*)	**Rocky Mt. juniper**	(*Juniperus scopulorum*)
Japanese boxwood	(*Buxus microphylla*)	**Eastern red cedar**	(*Juniperus virginiana*)
Glossy privet	(*Ligustrum lucidum*)	**Southern live oak**	(*Quercus virginiana*)
Indian hawthorn	(*Raphiolepis indica*)	**Southern magnolia**	(*Magnolia grandiflora*)
Yaupon holly	(*Ilex vomitoria*)	Japanese black pine	(*Pinus thunbergiana*)
Dwarf pittosporum	(*Pittosporum tobira*)		
Blue point juniper	(*Juniperus chinenses*)		
Hollywood juniper	(*Juniperus chinenses*)		
Spreading juniper	(*Juniperus chinenses*)		
Pyracantha	(*Pyracantha fortuneana*)		
Silverberry	(*Elaeagnus pungens*)		
Moderately Tolerant (6 - 8 dS m^{-1})			
Rosemary	(*Rosmarinus officinalis*)	Aleppo pine	(*Pinus halepensis*)
Spreading acacia	(*Acacia redolens*)	Russian olive**	(*Elaeagnus angustifolia*)
Bottle brush*	(*Callistemon viminalis*)	White pine	(*Pinus strobus*)
Bougainvillea*	(*Bougainvillea spectabilis*)	Arizona cypress	(*Cupressus arizonica*)
Coyotebush	(*Baccharis pilularis*)	**European olive**	(*Olea europaea*)
Japanese euonymus	(*Euonymus japonica*)	**Afghan pine**	(*Pinus eldarica*)
Oleander	(*Nerium oleander*)	**Piñon pine**	(*Pinus edulis*)
Texas sage	(*Leucophyllum frutescens*)	**Italian cypress**	(*Cupressus sempervirens*)
European olive	(*Olea europaea*)		
Tolerant (8 - 10 dS m^{-1})			
Four-wing saltbush	(*Atriplex canescens*)		
Highly Tolerant (>10 dS m^{-1})			
		Italian stone pine	(*Pinus pinea*)

* Subject to freeze damage unless protected
** Invasive, not recommended

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Chapter 2

A Performance Evaluation of Ground Covers for Low Maintenance Landscapes

Abstract:

Ornamental landscapes require considerable amounts of inputs, including but not limited to irrigation, mowing or pruning, fertilization, and pest management. However, school systems have limited budgets, which reduce their access to resources and labor hours. This has created an interest in ornamental plant species that can maintain aesthetic and other functional attributes while under low input conditions. The objective of this project was to identify ground covers that can compete with weeds and maintain aesthetic quality while under minimal maintenance. To explore this objective, we conducted a field experiment that evaluated ten candidate species under a realistic institutional grounds keeping setting in Corvallis, OR. Plants included 3 turfgrasses (*Festuca rubra L. ssp rubra* ‘Chantilly’, *Festuca rubra L. spp. commutata* ‘Longfellow II’, *Agrostis tenuis* Sibth ‘Puritan’), 6 forbs (*Vinca minor* L. ‘Illumination’, *Cotoneaster dammeri* C.K. Schneid‘Coral Beauty’, *Euonymus fortune* Sieb. ‘Kawensis’, *Herniaria glabra* L. ‘Green Carpet’, *Sedum spurium* Marschall von Bieberstein‘John Creech’, and *Ceanothus glorious* J.T. Howell ‘Point Reyes’) and 1 prostrate shrub (*Juniperus horizontalis* Moench ‘Blue Chip’) which were selected using a school system stakeholder group (The Plant List, 2013). All plots received daily irrigation for the first 4 months and subsequently discontinued for the remaining 8 months of the experiment. Plots are weeded and fertilized (4.88 g nitrogen m^{-2}) once annually. All of the species survived the trial, but the results determined species varied greatly in the ground cover they provided at the end of the trial. *A. tenuis* had the highest plant cover, followed by *F. Rubra*

'Chantilly' and *F. Rubra 'Longfellow'*. These turfgrasses performed at a much higher degree than the remaining plants; providing at least 60% cover to less than 25% for the remaining species. *S. spurium* and *J. horizontalis* performed the best among non-turfgrass species by providing 20-25% cover. The remaining ground covers all provided less than 7% plant cover. A strong inverse correlation between species ground cover and weed ground cover was identified over the course of the two years (R^2= 0.952), meaning higher values of percent ground cover taxa resulted in smaller values for percent weed cover. In this low maintenance/low input environment the turfgrasses greatly outperformed the forbs and prostrate shrub, meaning their range of application into landscapes is very large, especially fitting the niche of Oregon Schools' landscapes.

Introduction:

Oregon K-12 enrollment has been growing faster than the national average while expenditures for renovations and expansions are some of the lowest in the nation (Filardo et al., 2006). Issues like these are being faced among almost all public schools when budgets are cut due to the lack of funding, not just within this state. When considering the various maintenance and upkeep needs in and around the average school building and other structures, landscape improvement is often a low priority. For instance, when school grounds managers and other faculty were surveyed it was determined that the average public school sports field received a weekly mowing and 2 annual fertilizations of 48.82 kg ha^{-1} (Daviscourt et al., 2015). This level of maintenance is considerably less than minimal recommendations. To make matters worse these same grounds managers have a lot of area to maintain, Oregon public schools total 5,830 hectares of land dominated by turfgrass (Glander, 2016), which averages to about 4.7 hectares per school (Kowalewski et al., 2016). With such large areas to maintain and budget constraints, most schools have just enough time and money to mow during the growing season, while irrigation and fertilization is often a luxury that cannot be afforded. Low fertility and infrequent mowing gives weeds a better chance for germination and survival (DeBels et al., 2012; Elford et al., 2007; Frank et al., 2004). With minimal inputs a constant factor due to fractional budgets, these turfgrass conditions are extremely conducive to weedy circumstances. Oregon's school system may be one state that is in dire need of a solution, but many other state's schools could benefit from one as well. Expanding further, an affordable solution that allows for the reduction of weed populations under minimal input landscapes could be applied over a wide range of low maintenance/low input situations, not just within school landscapes.

A primary tactic in preventing weeds from establishing is to select a plant that develops a dense canopy. Many weed species are poor competitors for light, particularly during early life stages. Competitive reductions in available light during early growth stages is strongly correlated with reduced weed establishment (Kruidhof et al., 2008; Fisk et al., 2000). With plant competition theoretically doing most of the work against weeds, depletion of broadleaf weed seeds in the soil seed bank over time becomes much easier by managing weed populations at low densities, rather than at high densities (Buhler, 1999). Traditionally, ground covers are used to improve long term soil conditions, elevate crop yields, or reduce weed populations (Deguchi et al., 2007; Teasdale, 1996; Teasdale et al., 2007). With regard to successful weed reduction, commonly used living mulches in agriculture include clover species, annual ryegrass, hairy vetch, and alfalfa species (Ateh and Doll, 1996; Hiltbrunner et al., 2007; Teasdale and Daughtry, 1993; Huarte and Arnold, 2003). Most research regarding living mulches includes application in agricultural settings, and is rarely done in the urban landscape. Some scientific research has been conducted on ornamental ground covers and their effects on weeds, but these studies have been typically under benign or high input conditions (Eom et al., 2005; Foo et al., 2011).

The objective of this study was to quantify the effects of turf and ornamental ground covers on the incidence of weeds and to evaluate ground cover visual quality in a low input environment for possible applications in Oregon Public School landscapes.

Materials and Methods:

The performance of ten candidate groundcover taxa was evaluated in a common garden field trial. Research was initiated in May 2015 at the Lewis-Brown Horticulture Farm in Corvallis, OR. (44.551 Lat, -123.219 Long). This area receives roughly 100 cm of rain 9 months out of the year, with 3 months of droughty conditions in the summer. Snowfall is minimal, at about 7.6 cm. Soil type for the experimental area was a Chehalis silty clay loam. The experimental design was a randomized complete block design with 4 replications; individual plots were 0.55 m^2. The main effect for this experiment was ground cover plant: creeping red fescue (*Festuca rubra L. ssp rubra* 'Rubra Gaudin') 'Chantilly', chewings fescue (*Festuca rubra L. spp. commutata*) 'Longfellow II', colonial bentgrass (*Agrostis tenuis 'L.' Sibth*) 'Puritan', dwarf periwinkle (*Vinca minor L.*) 'Illumination', bearberry cotoneaster (*Cotoneaster dammeri C.K.* Schneid) 'Coral Beauty', wintercreeper (*Euonymus fortunei* Sieb.) 'Kawensis', creeping juniper

(*Juniperus horizontalis* Moench) ‘Blue Chip’, rupturewort (*Herniaria glabra L.*) ‘Green Carpet’, caucasian stonecrop (*Sedum spurium* Marschall von Bieberstein) ‘John Creech, and point reyes ceanothus (*Ceanothus gloriosus* J.T. Howell) ‘Point Reyes’.

Plant Selection

We used a stakeholder focus group to identify the ten candidate taxa evaluated in this study. This was done as part of a K-12 school grounds employee integrated pest management (IPM) training event held on 6 February 2015 at Sandy High School in Sandy, OR. At this event stakeholders were educated on 16 different low maintenance ground covers and turfgrasses. Management programs, pests and potential problems associated with each plant were highlighted using a PowerPoint presentation and then discussed in detail using open question and answer. During this time attendees also suggested and discussed other low maintenance ground cover plants. Attendees were then given a survey and asked to pick their favorite 5 of the 16 presented ground cover plants, or write in ground cover plants they wanted to see evaluated in this low maintenance ground cover study that was not already included. After tabulating the survey results, the group selected nine plants on the list, and collectively voted for one to be included (*C. gloriosus*) Potential ground covers not selected for research were as follows: hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. *x C. transvallensis* Burtt-Davy), Woolly yarrow (*Achillea tomentosa* L.), Creeping artemisia (*Artemisia viridis* Willd.), Cheddar pink (*Dianthus gratianopolitanus* Vill.), Silver carpet (*Dymondia margaretae* Compton), Blue woolly speedwell (*Veronica pectinata* L.), Pink carpet (*Delosperma cooperi* (Hook. f.) L. Bolus).

Installation and Maintenance

After the surveys were evaluated and the ground cover plants of choice were identified field research was initiated. Ground was renovated in preparation for ground cover establishment. The previous turfgrass stand was sprayed with a combination of Sethoxydim (Segment® herbicide, BASF, Ludwigshafen, Germany) and Glyphosate (Roundup®, Monsanto, St. Louis, MO) to kill all vegetation. The area was then prepared for planting by scalping the desiccated plant material to the soil surface with a mower and dethatching with a walk behind vertical-cutting machine.

The herbaceous ground covers (caucasian stonecrop, green carpet, dwarf periwinkle, wintercreeper, creeping juniper, bearberry cotoneaster, point reyes ceanothus) were transplanted from various container sizes ranging from 195 cm^3 to 2,835 cm^3. Plants were spaced evenly in all directions in their given plots according to nursery guidelines (Four Star Greenhouse, 2017; McShane's Nursery, 2015). Prior to planting a 5 cm layer of compost was incorporated into these plots. The turfgrasses (creeping red fescue, chewings fescue and colonial bentgrass) were seeded directly onto the soil at 22 g seed m^{-2} for the fescues and 4.88 g seed m^{-2} for the colonial bentgrass (Pacific Northwest Extension, 2010). After seeding, a thin layer of sawdust (0.25 cm) was applied to promote germination. During establishment from May to September 2015, irrigation was applied daily totaling at a rate of 2.5 cm per week, calibrated to apply this rate every other day. After September 2015, irrigation was discontinued for the remainder of the experiment; October 2015 to April 2017. Plots were fertilized once per year in the spring using Wilgro® Five Iron (25-3-10) at a rate of 4.88 g nitrogen m^{-2}. Plots were weeded in the spring May of 2016 and 2017, allowing a full year of foliage growth before each weeding event.

Response Variables

The response variables percent plant cover, percent weed cover and visual quality were measured every month from May 2015 to April 2017, whereas dry weed biomass was measure annually on April 2016 and April 2017. All measurements were taken at the plot level then averaged over the replicates per taxa (n=4). Horizontal percent plant and weed cover was obtained using the point intercept method and a 91.4 cm by 121.9 cm quadrant with 36 intersections. At these intersections the presence or absence of plant foliar cover (to species) and bare soil were tallied and used to quantify percent plant cover or weed cover as: Percent Cover = X (count of plant or weed) ÷ Y (total possible counts, or 36) (Stumpf, 1993). Visual quality ratings were assessed monthly on a scale of 1-5 where 1 equaled very poor quality, 5 equaled very good quality, and 3.5 or greater was regarded as acceptable.

Plots were weeded in April 2016 and 2017 to quantify dry above ground weed mass. For this process, the above ground weeds mass per plot (gram per 0.55 $m^{2)}$ was collected by hand, bagged, and dried for 72 hours at 50 °C. Plant material was weighed in grams with a Model 1,000 Metric Scale (Douglas Homs Corp., San Carlos, CA) scale with an accuracy of 1.0 g.

Statistical Analysis

Data variance for plant and weed cover, visual quality, and weed mass was analyzed using SAS 9.3 Proc Mixed (SAS Institute Inc., Cary, N.C.). Factors analyzed in this study were year and ground cover taxa. Data collected in April in 2016 and 2017 represent the factor year, because the plots were renovated to bare soil prior to planting in May 2015, and then weeded on April 2016 – one year after planting and again on April 2017 – two years after planting. Before ANOVA interactions were explored, tests for normality and homogeneity were performed using the Shapiro-Wilk's test and Levene's test. Each test produced results that failed to reject the null hypothesis that treatments acted differently in terms of distribution of residuals and equality of variance for the response variables plant cover, weed cover, weed mass, and visual. When ANOVA differences were significant, Fisher's Protected Least Significant Difference (LSD) was used to separate individual means at a 0.05 level of probability

Results:

Percent Plant Cover

The amount of ground cover achieved during the study differed among the candidate taxa, and these differences were consistent across the two years of the study even as overall cover grew. There were significant effects of plant taxa and year on ground cover, but no significant interaction between the two (Table 2.1). On April 2016 (one year after plating) the plant cover was (20.9% ± 3.4%, mean (n=4) ± SD), while on April 2017 (two years after planting and one year after the first weeding event) the plant cover was (36% ± 3.4%, mean (n=4) ± SD). Turfgrasses also showed similar growth trends over the course of two years when compared to other ground covers (Figure 2.1). The grass taxa attained consistently higher coverage than any of the candidate forb taxa (shrub included) over both years (Table 2.1). Two years after planting the grass taxa had average coverage of (73.1 ±3.4%, mean (n =4) ±SD) while the forbs+shrub taxa had an average coverage of (9.4 ±3.4%, mean (n =4) ±SD). All three of the grasses attained a cover greater than 66%, while 5 of the forb taxa attained less than 7% cover.

Percent Weed Cover

Weed cover percentages achieved during the study differed among the candidate taxa, and these differences were consistent across the two years of the study even as overall weed cover decreased. There were significant effects of plant taxa and year on weed cover, but no significant interaction between the two (Table 2.1). Across all plots, weed cover decreased from (75.5% ± 3.9%, mean (n=4) ± SD) (year one) to (53.1% ± 3.9%, mean (n=4) ± SD) (year two). The rate of growth of all ground cover weeds changed drastically from the first to second year as well; a sign of competition from more established ground cover taxa (Figure 2.2). The turfgrass taxa consistently attained fewer weed cover than any other type of taxa (forbs or shrub) (Table 2.1). Two years after planting the grass taxa had an average cover of (22.9 ±3.9%, mean (n =4) ±SD) while the forbs+shrub taxa had an average cover of (82.0 ±3.9%, mean (n =4) ±SD). All three of the grasses attained fewer than 30%, weed coverage, while 5 of the forb taxa allowed greater than 87% cover. Percent weed cover was found to be strongly correlated to percent taxa cover, in that greater/smaller percentages of weed cover translated directly to worse/better visual quality ratings (Table 2.3).

Dry Weed Mass

Weed biomass values weighed during the study differed among the candidate taxa, and these differences were consistent across the two years of the study even as overall weed biomass decreased. There were significant effects of plant taxa and year on weed biomass, but no significant interaction between the two (Table 2.1). From the first to second year after planting, across all plots, mean weed mass (279.5 gm^{-2}± 31.7 gm^{-2},mean (n=4) ± SD) decreased to (99.1 gm^{-2}± 31.7 gm^{-2},mean (n=4) ± SD). Like percent weed cover, the turfgrass taxa consistently attained fewer weed biomass values than any other type of taxa (forbs or shrub) (Table 2.1). Two years after planting the grass taxa had an average biomass of (35.0 ±31.7 gm^{-2}, mean (n =4) ±SD) while the forbs+shrub taxa had an average of (255.4 ±31.7 gm^{-2}, mean (n =4) ±SD). All three of the grasses attained fewer than 52 g m^{-2}, while 5 of the forb taxa allowed greater than 243 m^{-2}.

Visual Quality Ratings

The visual quality ratings observed during the study differed among the candidate taxa, and these differences were consistent across the two years of the study even as overall cover grew. There were significant effects of plant taxa on visual quality, but not from year (Table 2.1). Over the course of two years only the turfgrasses and J. horizontalis achieved acceptable visual quality ratings (3.5 or greater), with J. horizontalis surpassing the threshold only 4 months out of 24, and 5 of the forbs provided ratings of less than 1.1 on average (Figure 2.3). The grass taxa attained consistently higher ratings than any of the candidate forb taxa (shrub included) over both years (Table

2.1). Two years after planting, the grass taxa had average ratings of (3.7 ±0.15, mean (n =4) ±SD) while the forbs+shrub taxa had an average ratings of (1.3 ±0.15%, mean (n =4) ±SD). Visual quality was found to be strongly correlated to percent weed cover, in that greater/smaller percentages of weed cover translated directly to worse/better visual quality ratings (Table 2.3).

Discussion:

From the first to second year, plant cover increased by 15.1%, while weed cover was reduced by 22.4% and weed biomass was reduced by 64.5%. These findings are similar to work by Buhler et al. (1998) which determined that herbaceous perennial species are relatively susceptible to weed competition after planting because they are often slow to establish. Eom et al. (2005) found perennial groundcovers to significantly increase in weed suppressivity where plants were well established. Other research by De Abelleya et al. found similar results, in that when water was limited, established bermudagrass biomass increased while white clover biomass decreased (2008).

When evaluating the ten species in this study *A. tenuis*, *F. rubra 'Chantilly',* and *F. rubra 'Longfellow'* provided the greatest ground cover, and lowest weed populations. Similar to these findings, Hugie and Watkins (2016) found that under low fertility conditions colonial bentgrasss (*A. tenuis)* and hard fecue (*Festuca ovina*) can be a suitable low maintenance ground cover in Minnesota. Hugie and Watkins (2016) found that hard fescue provided better overall quality than colonial bentgrass, which typically browns out in the summer. *Festuca rubra* has been shown to reduce weed populations and even prevent weed growth in early parts of the season (Kron and Ferree, 2005). This attribute may have allowed the turfgrass to perform among the best in this study, even though weed cover ranged from 24-30% for the plant.

Considering the remaining ground cover plants, S. *spurium and J. horizontalis* provided great ground cover and fewer weeds that the remaining ground cover plants, *V. minor, C. dammeri, C. gloriousus, E. fortunei,* and *H. glabra*. Similar to these findings, Foo et al. (2011) found that *Sedum* and *Juniperus* species provided high ranking ground coverage in comparison to 12 different plants with minimal maintenance (weeding and fertilization). Foo et al (2011) found that *Acaena inermis* 'Purpurea' and *Muehlenbeckia axillaris* provided the greatest ground cover in their research. Contrary to these findings Eom et al. (2005) studied 15 ground covers and found *Sedum* and *Juniperus* species performed the worst in terms of biomass after two years of growth in minimal maintenance conditions. The work conducted by Eom et al. did not measure percent cover, but rather above ground biomass, which exhibits bias towards taller growing ground covers. *Sedum* species have been shown to provide fluctuations in plant density throughout the season leaving it susceptible to weed encroachment (Foo et al., 2011). Foo et al (2011) also found the *Juniperus* species open to weed encroachment in the earlier stages of growth as it is slow to establish. In terms of weed mass accrued over time *Juniperus* and *Sedum* species have been seen to perform similarly (Foo et al., 2011). Other studies show sedum can provide fairly weed free plots, as well as *Vinca minor*; where "successful groundcovers possessed dense foliage, strongly reducing light transmittance at the soil surface, and emerged relatively early in spring (Eom et al., 2005)." In general other studies concluded that *Sedum*, *Juniperus*, and *Vinca* species were not superior compared to their fellow treatments (Eom et al., 2005; Foo et al., 2011).

As seen in this experiment, previous studies have found that the desirability of ornamental landscape plants is correlated with their ability to maintain high cover and suppress weeds. Weedy landscapes tend to be perceived as unattractive, not well-cared for, and messy, but such a landscape was also rated as appearing to be natural and requiring little maintenance (Nassauer, 1993). Nassauer (1993) found significant correlations in these weedy landscapes between attractiveness, care, and neatness as well. This ground cover study, as well as Nassauer's, show correlations between weed populations and attractiveness, but there are differences in the perception of weeds and their associated maintenance levels. Suburban respondents from Nassauer's study were more likely to think weedy landscapes require low maintenance, whereas Oregon school landscape managers correlate weeds with increased landscape maintenance requirements (based on input from IPM grounds training meetings). These opinions suggest differing expectations of landscape quality between the two groups of survey respondents; showing limitations or biased results from geographically specific areas and audiences.

Conclusion:

Discontinuing irrigation during the study showed increases in plant cover (15.1%) and reductions in weed cover (22.4%). *Agrostis tenuis* provided the most plant cover (85%), lowest weed populations and highest quality ratings. The next highest coverage provided were by *F. rubra 'Chantilly'* (68%) and *F. rubra 'Longfellow'* (66%). Following the grasses, S. *spurium* (24%) *and J. horizontalis* (22%) provided relatively high ranking plant density and reduced weed populations in comparison to the remaining herbaceous ground cover plants. The lowest performing plants were *V. minor*, *C. dammeri*, *C. gloriousus*, *E. fortunei*, and *H. glabra* , which provided the lowest plant density, substantial weed encroachment and very poor quality ratings. Based on the costs of these ground covers (whole price) and their associated percent cover values, turfgrasses are more realistic options for implementation over large landscaped areas.

Figures:

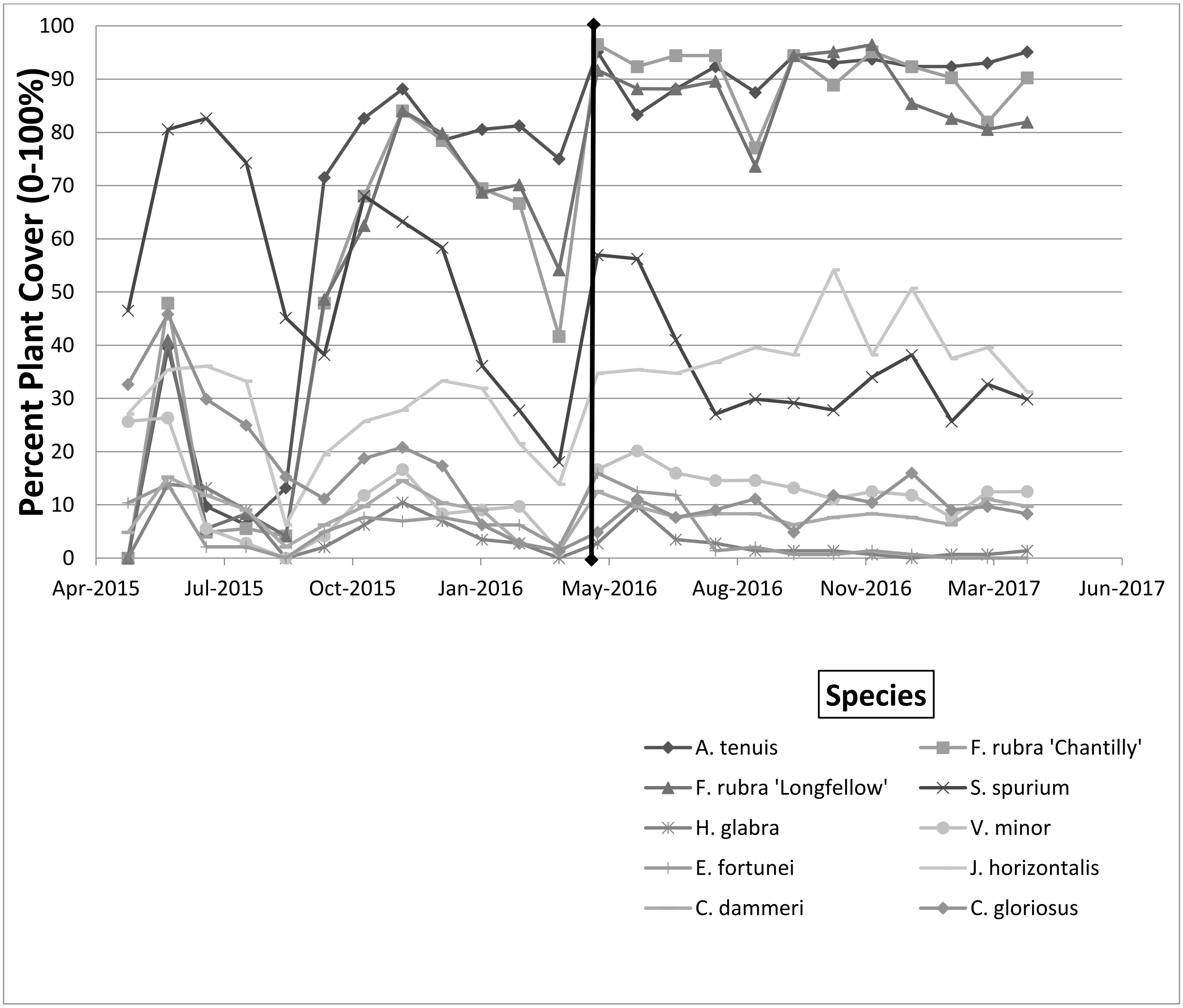

Figure 2.1: The growth of ten candidate low-input ground cover taxa over a two year period in Corvallis, OR. Growth was measured as monthly percent foliar cover. Values are mean (n = 4) plot censuses. The line break at May 2016 denotes the time of annual weeding.

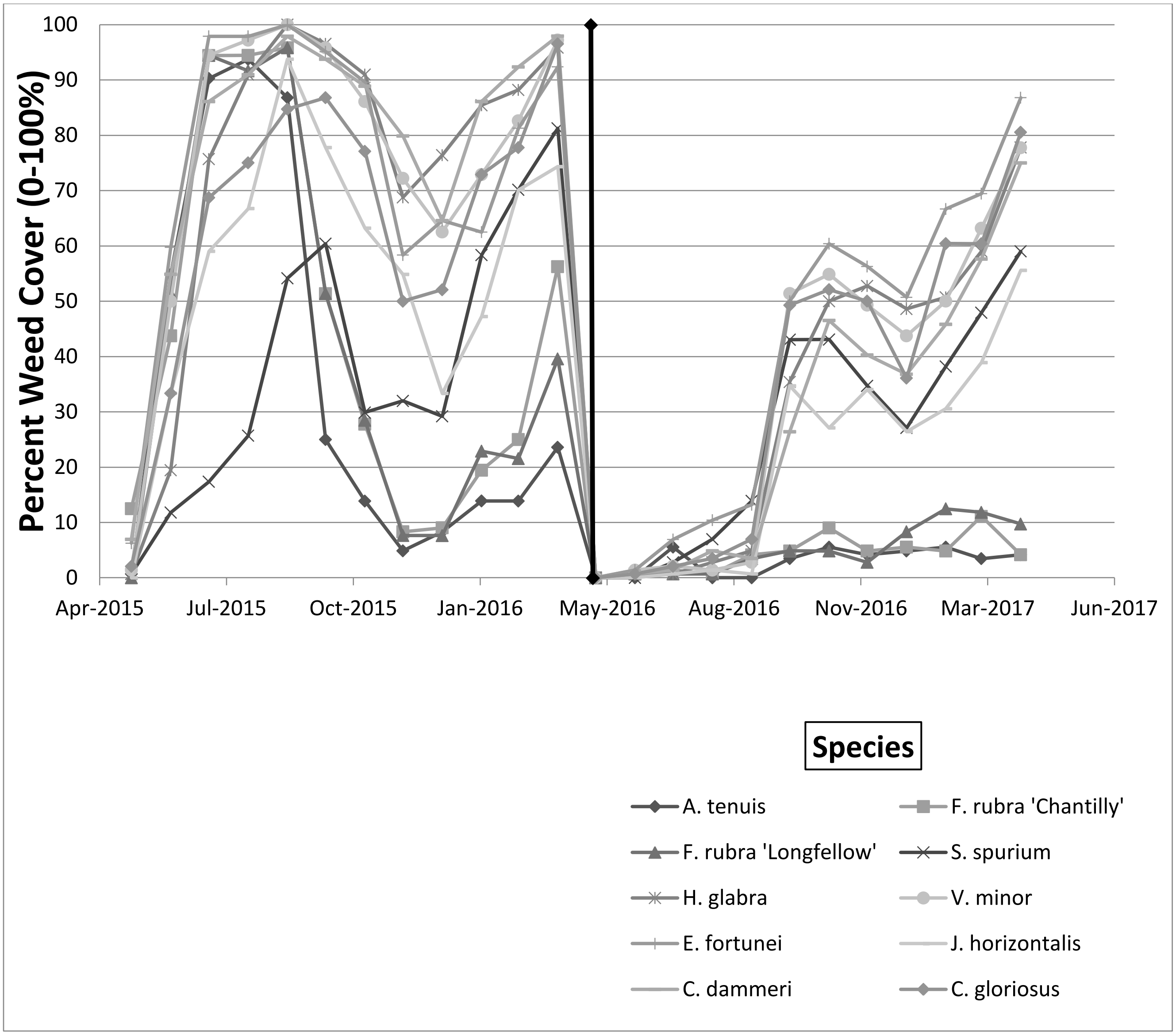

Figure 2.2: The growth of weeds within ten candidate low-input ground cover taxa over a two year period in Corvallis, OR. Growth was measured as monthly percent foliar cover of weeds. Values are mean (n = 4) plot censuses. The line break at May 2016 denotes the time of annual weeding.

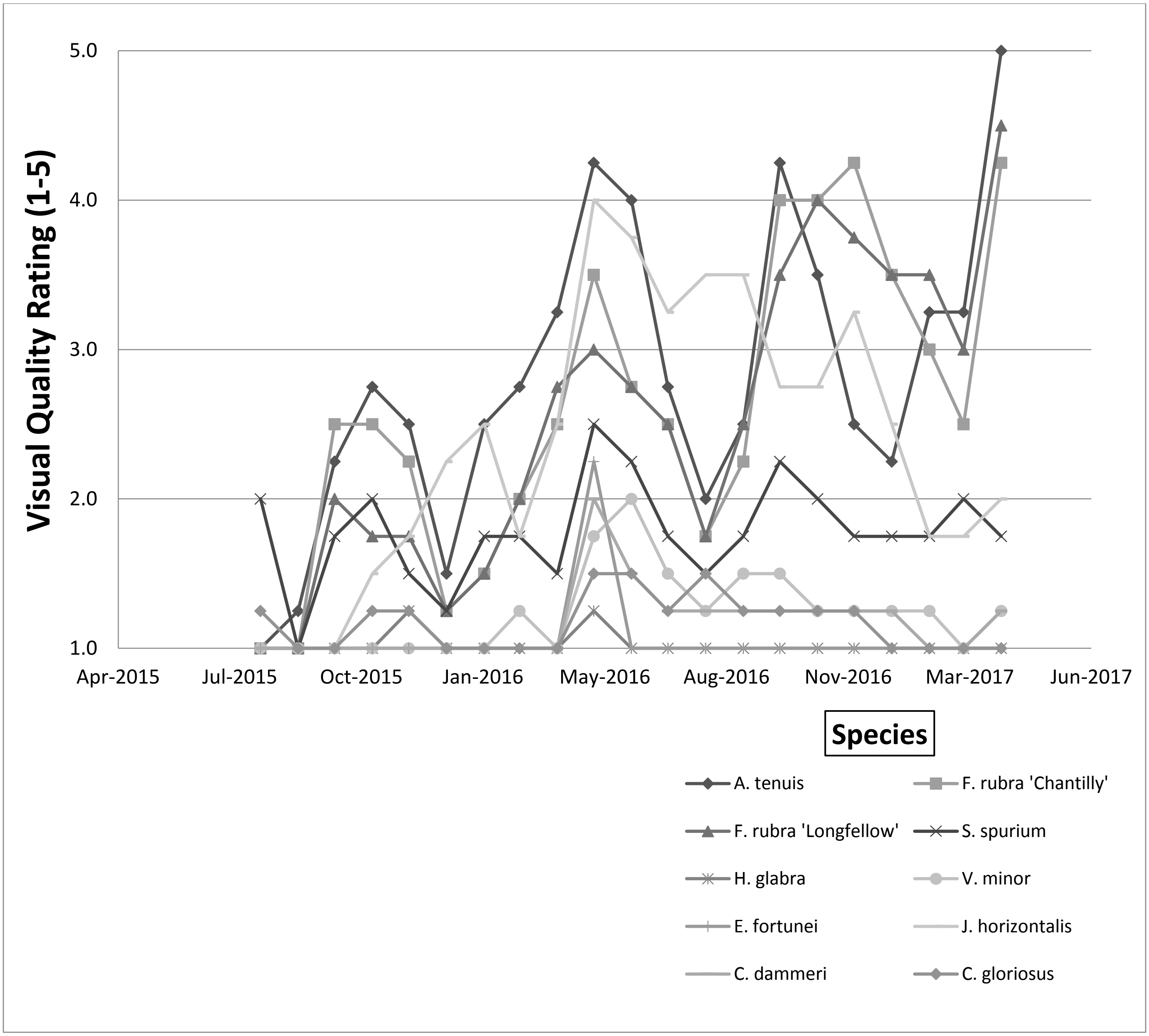

Figure 2.3: The visual quality of ten candidate low-input ground cover plant taxa over a two year period in Corvallis, OR. Quality was measured as monthly visual quality on a scale of 1-5 where 1 equals very poor quality, 5 equals very good quality, and 3.5 or greater is regarded as acceptable. Values are mean (n = 4) plot censuses. The line break at May 2016 denotes the time of annual weeding.

Tables:

Table 2.1. Analysis of variance and effects of year and plant ground cover and the interaction between these factors on percent ground cover, percent weed cover, dry mass, and plant quality in Corvallis, OR in April 2016 (one year after planting) and 2017 (two years after planting, and one year after the annual weeding event).

Source of Variation	DF Num	DF Den	% Plant Cover	% Weed Cover	Dry Weed Mass (g)	Quality[z]
			--------------------------Pr>F			------------------------------
Year	1	57	***	***	***	ns
Ground Cover	9	57	***	***	***	***
Year X Ground Cover	9	57	ns	ns	ns	ns

Year	Percent Plant Cover (0-100%)		Percent Weed Cover (0-100%)		Dry Weed Mass (g m^{-2})		Quality (1-5)	
April 2016	20.9	b[y]	75.5	b[y]	279.5	b[y]	2.3	a[x]
April 2017	36.0	a	53.1	a	99.1	a	1.75	a

Species	Percent Plant Cover (0-100%)		Percent Weed Cover (0-100%)		Dry Weed Mass (g m^{-2})		Quality (1-5)	
Agrostis tenuis 'Puritan'	85.1	a[y]	13.9	a[y]	31.5	a[y]	4.1	a[x]
Ceanothus gloriousus 'Point Reyes'	4.9	d	88.5	d	245.4	bcd	1.0	e
Cotoneaster dammeri 'Coral Beauty'	5.6	d	86.5	d	337.5	e	1.1	e
Euonymus fortunei 'Kawensis'	1.1	d	89.6	d	243.1	bcd	1.0	e
F estuca rubra 'Chantilly'	68.1	b	24.7	ab	21.8	a	3.6	b
Festuca rubra 'Longfellow'	66.0	b	30.2	b	51.9	a	3.4	b
Herniaria glabra 'Green Carpet'	0.7	d	86.8	d	309.1	de	1.0	e
Juniperus horizontalis 'Blue Chip'	22.6	c	65.0	c	171.6	b	2.3	c
Sedum spurium 'John Creech'	24.0	c	70.1	c	216.1	bc	1.6	d
Vinca minor 'Illumination'	7.0	d	87.5	d	264.8	cde	1.1	e
Standard Deviation (SD)	± 3.4		± 3.9		± 31.7		± 0.15	

***Significant at a 0.001 level of probability; ns = not significant at a 0.05 level of probability.

[z] Monthly visual quality on a scale of 1-5 where 1 equals very poor quality, 5 equals very good quality, and 3.5 or greater is regarded as acceptable.

[y] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) $P \leq 0.05$.

[x] Means denoted with same letter are not significantly different according to Dunn's pairwise comparisons.

Table 2.2. Correlation analysis for percent ground cover taxa across percent weed cover in Corvallis, OR in April 2016 and 2017 (grouped).

Source of variation	Parameter estimate	*Pr* > F	R^2
Intercept	91.486	***	0.952
Percent plant cover (0-100%)	-0.980	***	

***Significant at a 0.001 level of probability.

Table 2.3. Correlation analysis for percent weed cover across visual quality in Corvallis, OR in April 2016 and 2017 (grouped).

Source of variation	Parameter estimate	*Pr* > F	R^2
Intercept	108.572	***	0.826
Visual quality (1-5) ^{z}	-22.262	***	

***Significant at a 0.001 level of probability.

z Monthly visual quality on a scale of 1-5 where 1 equals very poor quality, 5 equals very good quality, and 3.5 or greater is regarded as acceptable.

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