FIRE AND FALSE BROME: HOW DO PRESCRIBED FIRE AND INVASIVE *BRACHYPODIUM SYLVATICUM* AFFECT EACH OTHER?

by

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THESIS ABSTRACT

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Brachypodium sylvaticum, an invasive grass in Oregon, has the potential to cause ecosystem collapse by altering forest fire regimes. To examine interactions with fire we divided two sites in the Willamette National Forest into eight units and randomly selected half for treatment with prescribed fire in spring 2011. *B. sylvaticum* did not affect prescribed fire intensity or severity. However, fire severity negatively affected *B. sylvaticum* abundance ($F_{4,43}$ = 5.01, P = 0.002). In the field, prescribed fire decreased germination ($F_{1,96}$ = 7.54, P = 0.007, R^2 = 0.46) in comparison with the control (0.14±0.07/plot burned versus 0.30±0.16/plot controls). Similar to abundance and germination, fire severity was the driver significantly affecting dispersal ($F_{4,27}$ = 5.50, P = 0.002). These results indicate that hot fires have the potential to control the grass, but low severity fires will likely make it worse.

This thesis includes previously unpublished coauthored material.

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For my mother and personal hero, Beth Poulos.

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CHAPTER I

INTRODUCTION

This thesis will appear as an article with a listed coauthor, Barbara A. Roy. One of the principal ecological challenges currently is the remediation of non-native invasive plant species before they irreparably transform ecosystems by altering disturbance regimes (D'Antonio and Vitousek 1992), available abiotic resources, native vegetation structure or patterns of native establishment and recruitment (Vitousek et al. 1996, Gordon 1998). The non-native grass *Brachypodium sylvaticum* (Huds.) P. Beauv., or false brome, is an example of a species that could potentially cause major ecosystem change through each of these different pathways.

Natively, *B. sylvaticum* is found in temperate zones throughout most of Eurasia including Europe, Russia, China, Japan, India, Indonesia as well as Lebanon, Syria, Iran, Algeria and Eritrea (Roy 2010). It is a perennial, wind-pollinated grass (Rosenthal et al. 2008) that tolerates the full range of possible light conditions from deep shade to open canopy (Murchie and Horton 2002, Hrusa 2003, Parks et al. 2005, Corney et al. 2008, Palo et al. 2008). Because shade tolerant taxa are relatively unusual, this characteristic may give *B. sylvaticum* a competitive advantage (Sutherland 2004, Martin et al. 2009) as it has the ability to utilize and exploit a variety of environments.

First collected in Oregon in 1939 (Chambers 1966), it is now considered extremely invasive and has been declared a noxious weed in California, Oregon and Washington (CDFA 2009, NWCB 2009, ODA 2009). A rapid seed disperser (Petersen and Philipp 2001), the grass' lengthy awns work into animal fur (Heinken and Raudnitschka 2002), which facilitates transportation. It has been noted as far east as

Missouri, New York, and Virginia (Roy 2010), likely indicating range expansion. False brome is associated with logging practices, as it is transported on equipment and crews (Fletcher 2009, USDA Forest Service et al. 2009). It is also moved by human recreational activities, and by rivers and streams (Roy 2010). Similar to many invasive species, in its non-native range it is highly correlated with disturbed areas. For example, a recent study found that invasions were concentrated within 30m of human-use corridors such as power lines and trails (Holmes et al 2007).

B. sylvaticum grows into thick, lawn-like monocultures, and invasive grasses in general have been shown to crowd out native plants and decrease recruitment of conifers (Powell et al. 1994, Lehmkuhl 2002, Kruse et al. 2004). Because forests in Western Oregon have not evolved with an understory of dense grass, this change in ecosystem structure could have a variety of unforeseen effects. Besides reducing natural native tree regeneration, the loss of biodiversity could result in a "trophic cascade" where higher levels of invertebrates and other wildlife species are negatively affected (Zuefle et al. 2008).

A non-native grass introduced to an area is sometimes enough to set in motion the "grass-fire cycle" (D'Antonio and Vitousek 1992). Often times, invasion also interacts with human mediated land use change, creating a positive feedback loop as more disturbed areas are more at risk for invasion (DiTomaso et al. 2006). Grasses increase the probability of fire (Keeley 2006) but they typically create lower intensity fires than dense shrub understories (Zschaechner 1985), which can have the effect of preserving the seed survival rate (Keeley 2006). With an increased accumulation of fine, flashy fuels, grasses can increase fire frequency and area burned, then post-fire, out-compete native species for space and resources. As the invading species increases in abundance, so does the strength of the grass-fire cycle, and essentially, it becomes self-propagating unless something intervenes to stop its progress. In otherwords, *B. sylvaticum* might alter the ecosystem in ways that increase the likelihood of its own success.

B. sylvaticum is changing forest fuel structure with the addition of thick thatch layers made up of each year's senesced growth, which could affect the fire regime, defined as the characteristic fire frequency, intensity, severity and spatial/temporal scales of a given area (Gill 1975, Pausas and Keeley 2009). For the purposes of our study, we have defined fire intensity as the measure of energy output by a fire (Keeley 2009). Fire severity describes the actual ecosystem effects from fire (i.e., changes to vegetation, percent scorch, fuel consumed etc.) and is not to be confused with intensity (Keeley 2009).

Is *Brachypodium sylvaticum* a species capable of initiating a grass-fire cycle? If so, the results could have tremendous implications for the forest ecosystems throughout the Western U.S. Not only are there potential severe ecosystem effects, but also financial ones. This grass is invading the west side of the Cascade mountains, an area that is highly valued for its timber production. It is imperative that we fully understand how this particular grass interacts with fire in these forests. Employing the use of prescribed fire, our experiment focused on two main questions: 1. Does *B. sylvaticum* affect fire intensity and/or severity?, and 2. Does treatment with fire affect *B. sylvaticum* abundance, germination, or dispersal?

There were two possible outcomes to each question:

1.a) By increasing finer fuels, *B. sylvaticum* could increase fire intensity and/or severity (Anzinger and Radosevich 2008, USDA Forest Service et al. 2009).

1.b) Because *B. sylvaticum* remains green throughout the summer, a reduction in fire intensity and/or severity could occur in areas with high false brome abundance (Anzinger and Radosevich 2008, False Brome Working Group 2009).

2.a) Treatment with fire, if timed appropriately (e.g., spring burns target elongated tillers, resulting in a decrease in abundance), has been a successful tool in controlling some invasive perennial grasses (DiTomaso et al. 2006). If prescribed fire decreases false brome abundance (germination and/or dispersal), then it could be a useful management tool.

2.b) On the other hand, prescribed fire will increase light levels due to a reduction in canopy, increase exposed soil, and increase the likelihood of seed dispersal on crew and equipment, which decreases the usefulness of prescribed fire for control (DiTomaso et al. 2006). Also, with the potential of instigating a grass-fire cycle, fire may actually facilitate the spread and propagation of *B. sylvaticum*.

CHAPTER II

METHODS

Study Sites

The Cascade Range of the Western U.S. is known for its steep, volcanic terrain with mean annual precipitation exceeding 2500 mm, falling October through April as rain in lower elevations and snow in higher areas (Cissel et al. 1999). The Willamette National Forest (WNF) stretches along the western side of these slopes in Oregon, and has a historical fire patch size of about 10-160 hectares (ha), excluding very large, stand-replacing fires that infrequently occurred and created patches some thousands of ha in size (Cissel et al. 1999).

Two sites within this forest were selected for study due to preexisting infestations of *B. sylvaticum* (Site 1: 44° 09’40.30” N x 122° 02’48.60” W; Site 2: 44° 9’32.20” N x 122° 3’23.98” W). Each site is at about 760 meters in elevation and dominated by Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) coniferous forest. Site 1 has is 9.71 hectares and Site 2 is 24.69 hectares, together totaling 34.4 hectares. Both sites were divided into eight subunits with half of the subunits in each site randomly selected for treatment with prescribed fire and the other half left as controls. To monitor cover of *B. sylvaticum* pre- and post-fire treatment, sixteen 1 m^2 plots containing *B. sylvaticum* in each site (2 randomly located per subunit). To determine whether fire influences dispersal, we set up thirty-two 1 m^2 plots without *B. sylvaticum* (zero cover was the goal but some plots were later found to have <0.5% cover or one non-reproductive seedling), positioned perpendicular to the *B.*

sylvaticum plots. Starting with <0.05% cover in the dispersal plots we measured *B. sylvaticum* cover over time to study the rate of spread to new areas. Each site thus had eight burned and eight unburned $1m^2$ *B. sylvaticum* plots as well as 16 burned and 16 unburned $1m^2$ dispersal plots for a total of 96 plots [Fig. 1].

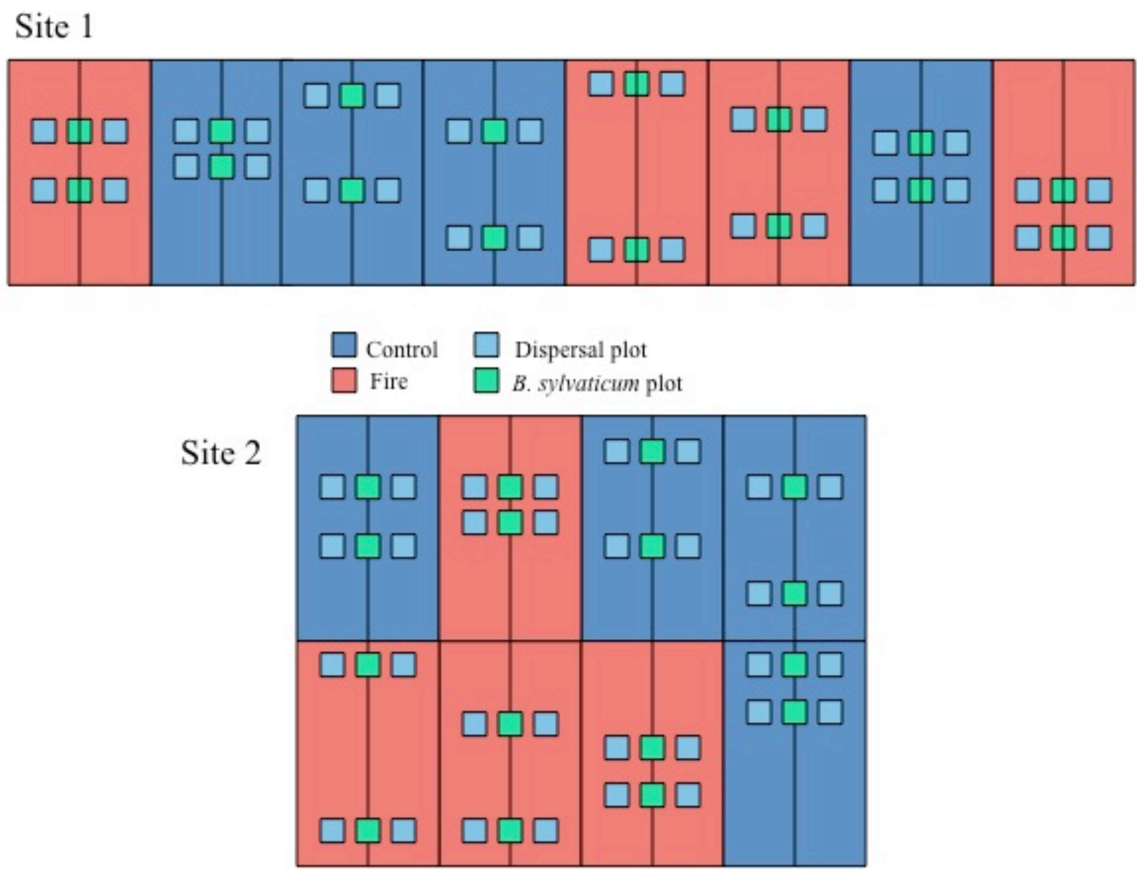

Figure 1. Plot Layout – A schematic representation of the plot layout in the sites.

To be sure the treatments and controls were similar before starting, and to enhance our ability to detect the influence of the fire treatment, we collected both pre- and post-treatment data. Prescribed fire treatments were applied on June 22, 2011 to Site 1 and July 10, 2011 to Site 2. While about two weeks separated the fires, in terms of fire readiness, the sites were similar at the time of ignition (the second site was more vegetated and thus required more time to lose fuel moisture and become acceptably flammable).

Field Experiment

Pre-treatment measurements were taken in the fall of 2010 (vegetation) and spring of 2011 (fuels). All post-treatment measurements that were the most sensitive to weather influences (for example, burn severity is partially assessed by levels of ash on the ground) were gathered the day each prescribed burn treatment was applied. General vegetation monitoring was conducted in the pre-burn fall of 2010, post-burn fall of 2011 and fall 2012, while seedling counts were taken in the spring and fall of 2012. The measurements taken were:

Plot Level-- Percent cover of B. sylvaticum, other vegetation, rock/dirt and total wood was estimated (fall 2010, 2011, 2012, and day of fire treatment 2011) visually with a 1 m^2 quadrat and using a fist as approximately equal to 1% of the plot area.

Canopy cover was measured using a convex spherical densiometer pre- and post-treatment for each of the four sides of the quadrat, and the readings were averaged for an overall plot measurement. Slope was measured once, pre-treatment, with an inclinometer.

Burn Severity was measured as an index on the day of fire treatment for each burn plot and was assessed using a combination of substrate and vegetation characteristics (i.e., levels of char or scorch, amount of woody debris or vegetation consumed, ash levels/colors, etc.) (USDI National Parks Service 2003). The scale is ranked in descending order with a category 5 severity as the lowest (unburned) and category 1 as highest severity (heavily burned). Those plots with a classification of 5 had fire applied but displayed relatively little visible effects from burning, whereas the control plots are different in that no fire ever entered into the plot whatsoever.

Fire intensity was measured using the observed plot temperature during fire treatment and was captured with temperature sensitive paints (Iverson et al. 2004). Because 60° C is the the lowest temperature capable of causing lethal tissue damage (Wally et al. 2009) and forest fires exhibit high temperatures ranging from 800° to 900° C (Wally et al. 2009), we chose seven different paints, each sensitive to a specific temperature (79°, 149°, 253°, 343°, 454°, 649°, 816°C) manufactured by OmegaLaq®. Paints were applied to copper garden tags in descending order, with each paint present on every tag, and a blank tag was secured to the painted tag for protection from the elements. Tags were secured to a stake and arranged in pairs: one at ground level and the other suspended 20 cm with 2 replicates per plot for a total of four tag readings [Fig. 2]. Stakes were placed in both the northwest and southeast plot quarters and approximately three inches away from the nails measuring duff consumption. Tags were set up about prior to treatment with fire.

Figure 2. Temperature Sensitive Paints Set Up – Replicated twice in each plot for a total of 4 tags per plot (two at 20 cm, two at 0 cm).

B. sylvaticum seedling counts were taken post-treatment in the spring and fall of 2012. These measurements were used to address the question of whether fire treatment affected the next year's seed bank (control vs. treatment plots). Due to extremely high densities of *B. sylvaticum* seedlings and established individuals in many plots, field counts were taken only at the quarter-plot scale. Only non-reproductive individuals less than 3-4 inches in height and obviously not more than one season old were counted as seedlings. Counts were consistently taken from the northeast corner of each plot.

Site Level-- Ambient temperature and relative humidity at time of burn treatment was recorded for each site and communicated by the US Forest Service fire personnel to us.

Greenhouse Experiment

For the greenhouse experiment, 4 soil cores (5 cm in diameter x 5-7cm deep) were taken just outside each plot and composited. The soil for each plot was added to a sand and sphagnum mixture in a 1.5 to 4 part ratio (soil to sand/sphagnum) and planted out into sterile 10 x 20 inch trays. These were randomly arranged in the greenhouse, watered every other day and exposed to 16 hours of light per day for one week, followed by six weeks of 12 hour days. Only *B. sylvaticum* and other graminoids were identified and counted.

Statistical Analysis

To gain an understanding of which aspects of the fire treatment, if any, were important, we broke the fire treatment down further into intensity of treatment and severity of treatment, and these two variables were run in independent analyses. Analyses on overall fire effects included all plots, control and burn. Because severity/intensity metrics only occurred in burned units, we ran analyses only on burn plots and excluded controls. All percent cover and proportion data were logit transformed to facilitate ease of interpretation (Warton and Hui 2011). **JMP® Pro 9.0.2** statistical software (SAS. 2010) was used for statistical analyses and Microsoft Excel was used for data keeping.

Study Questions

Does B. sylvaticum *Affect Prescribed Fire?* Since fire can be influenced by an array of environmental variables, any of which could potentially be driving the system, we devised a method of analysis to control for these variables and therefore distill out the effect of the grass alone on fire. Analyzing only the burn plots, we first tested for multicollinearity of variables, which was not an issue (the highest variance inflation factor (VIF) was 2.7). Second, we applied a backwards stepwise regression excluding all plots containing *B. sylvaticum* cover pre-treatment while including all plot-level environmental variables that could potentially have an effect on fire (slope and % cover of fuels, canopy, and other vegetation). Third, taking the calculated intercept and slopes for each of the significant variables, an expected fire variable (EFV) was calculated for all plots using a formula structured such that each x is an environmental variable exerting a significant effect on the system:

$$EFV = Intercept + (Slope_1)x_1 + (Slope_2)x_2 + (Slope_3)x_3 + (Slope_4)x_4, \text{ etc.}$$

From this number, we then calculated a corrected fire variable (CFV) by subtracting the EFV from the actual observed fire variable. Lastly, CFV was regressed against *B. sylvaticum* cover present in plots pre-treatment using a simple linear regression. This approach was applied to all the sites together, as well as separated by site.

Does Prescribed Fire Affect Abundance of B. sylvaticum*?* To determine how prescribed fire affects the percent cover, or abundance of *B. sylvaticum*, we employed a repeated measures multivariate analysis of variance (MANOVA). Comparing each plot's percent cover of *B. sylvaticum* over time, we have three dependent measurements of abundance (one pre-treatment and two post treatment). We looked at differences in the means over time using the measured explanatory fire variables (i.e., severity and intensity of treatment).

Does Prescribed Fire Affect B. sylvaticum *Germination in the Field?* To assess the effects of prescribed fire treatment on germination, we log transformed the spring 2012 seedling counts and applied a Type I, or sequential test, to control for the variation contributed by the pre-treatment abundance of *B. sylvaticum* in each plot. In this way, we were able to control for the influence of previously established individuals contributing to the seedling counts and strictly assess the effect of fire treatment on any resulting germination. We regressed the log transformed seedling counts in a sequential test against the logit transformed pre-treatment *B. sylvaticum* abundance, treatment and site. We treated site as a random effect in a restricted maximum likelihood (REML) model so that our results would be generally applicable instead of only pertinent to our specific study sites.

Does Prescribed Fire Affect B. sylvaticum *Germination in the Greenhouse?* We repeated the sequential test described for the field counts above again for the greenhouse data. Log transformation did not produce normal residuals of the greenhouse seedling counts, so we used a Box Cox power transformation.

Does Prescribed Fire Affect B. sylvaticum *Dispersal?* For this statistical model, only the dispersal plots were analyzed (i.e., only the plots that contained <0.5% cover of *B. sylvaticum* at the inception of the study), and a repeated measures MANOVA was applied to look at the change in the grass's abundance over time and with treatment.

CHAPTER III

RESULTS

Does B. sylvaticum *Affect Prescribed Fire?*

When intensity and severity are treated as continuous data, and the sites are combined together, pre-treatment *B. sylvaticum* did not affect prescribed fire intensity ($F_{1,29}$ = 0.40, P = 0.53, R^2 = 0.01) or severity ($F_{1,27}$ = 0.27, P = 0.61, R^2 = 0.01). When each site was analyzed separately, intensity remained insignificant (Site 1: $F_{1,29}$ = 1.42, P = 0.24, R^2 = 0.05, and Site 2: $F_{1,17}$ = 0.05, P = 0.83, R^2 = 0.003) [Fig. 3]. However, pre-treatment *B. sylvaticum* in Site 1 trended towards significance with a positive relationship ($F_{1,10}$ = 4.04, P = 0.08, R^2 = 0.34); higher abundances of the grass trend towards having higher severity fires [Fig. 3]. Pre-treatment *B. sylvaticum* in Site 2 did not have a significant effect on fire severity ($F_{1,17}$ = 0.24, P = 0.63, R^2 = 0.02).

Does Prescribed Fire Affect Abundance of B. sylvaticum*?*

When looking at treatment versus controls, prescribed fire did not affect abundance of *B. sylvaticum* ($F_{1,62}$ = 0.66, P = 0.42). We observed that there was no significant relationship between intensity of treatment and false brome abundance, although the results were very close to significant ($F_{1,46}$ = 3.64, P = 0.06) [Table 1]; intensity was negatively associated with false brome cover.

Severity of fire treatment on *B. sylvaticum* abundance is the true driver of change in this system ($F_{4,43}$ = 5.01, P=0.002). [Table 2 & Fig. 4] There was no obvious change in percent cover until 2012 when those plots which burned with the lowest severity actually showed a marked increase in abundance [Fig. 4].

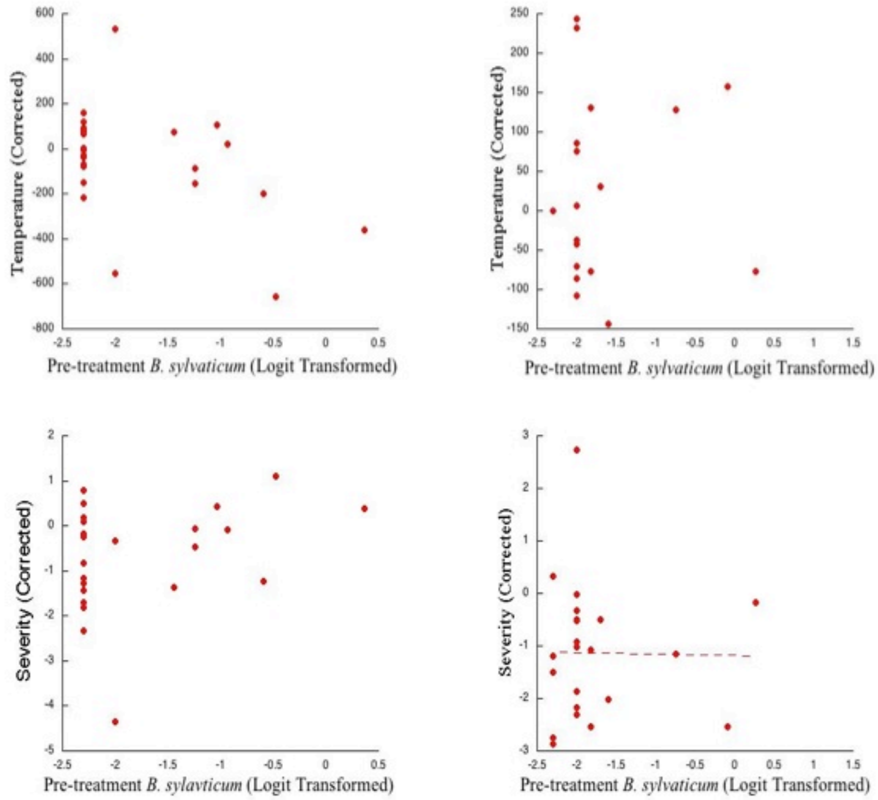

Figure 3. Pre-treatment *B. sylvaticum* Abundance on Fire Intensity/Severity - After correcting for variation due to other environmental variables, pre-treatment *B. sylvaticum* abundance did not have a significant effect on fire intensity, as shown for Site 1 in the upper left graph ($F_{1,29}$ = 1.42, P = 0.24, R^2 = 0.05) and Site 2 in the upper right ($F_{1,17}$ = 0.05, P = 0.83, R^2 = 0.003). Pre-treatment *B. sylvaticum* in Site 1, the lower left graph, trended towards significance with higher abundances of the grass trend towards having higher severity fires (lower values of severity indicate higher severity burns) ($F_{1,10}$ = 4.04, P = 0.08, R^2 = 0.34). Pre-treatment *B. sylvaticum* in Site 2, the lower right graph, had a significant negative effect on fire severity ($F_{6,17}$ = 3.57, P = 0.04, R^2 = 0.68); plots with higher abundances of the grass had lower severity fires (lower values of severity indicate higher severity burns).

Table 1. Fire Intensity Affects *B. sylvaticum* Abundance.

Between	**MS**	**F**	**df**	**P**
All	0.08	3.64	1, 46	0.0627
Intercept	0.08	3.89	1, 46	0.0547
Intensity	0.08	3.64	1, 46	0.0627
Within				
All	0.16	3.56	2, 45	0.0368*
Time	0.09	2.00	2, 45	0.1475
Time*Intensity	0.16	3.56	2, 45	0.0368*

Table 2. Fire Severity Affects *B. sylvaticum* Abundance.

Between	**MS**	**F**	**df**	**P**
All	0.47	5.01	4, 43	0.0021*
Intercept	0.42	18.17	1, 43	0.0001*
Severity	0.47	5.01	4, 43	0.0021*
Within				
All	0.49	4.54	8, 84	0.0001*
Time	0.03	0.61	2, 42	0.5487
Time*Severity	0.49	4.54	8, 84	0.0001*

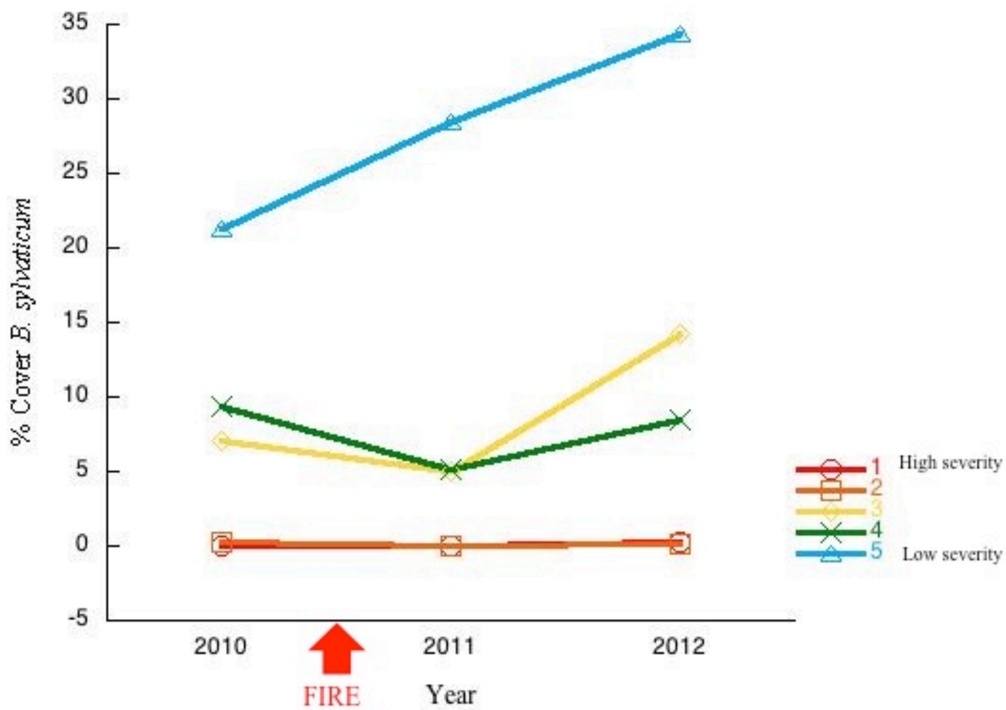

Figure 4. Severity of Treatment and *B. sylvaticum* Abundance – MANOVA results showed plots which burned with the lowest severity showed an increase in abundance ($F_{4,43}$ = 5.01, P=0.002).

Does Prescribed Fire Affect B. sylvaticum *Germination in the Field or in the Greenhouse?*

Analyzing the seedling counts taken in the forest the year following treatment, prescribed fire had an overall negative effect on false brome germination in the field ($F_{1,96}$ = 7.54, P = 0.007, R^2 = 0.46) [Fig. 5]. Site, a random effect in the REML model, only explained only 6.3% of the variance in the data. Looking more closely at the fire effects, we saw that severity of treatment ($F_{4,48}$ = 1.62, P = 0.19, R^2=0.49) and intensity of treatment ($F_{1,48}$ = 2.11, P = 0.16, R^2=0.47) separately were not significant influences. In the greenhouse experiment, we did not see a significant effect of treatment (fire vs. controls) ($F_{1,96}$ = 1.00, P = 0.32, R^2 = 0.05) or intensity of treatment ($F_{1,48}$ = 0.76, P = 0.39, R^2 = 0.06) on germination. We did, however, observe a significant effect for fire severity ($F_{1,48}$ = 5.05, P = 0.03, R^2 = 0.13); higher severity fire led to lower germination [Fig. 6].

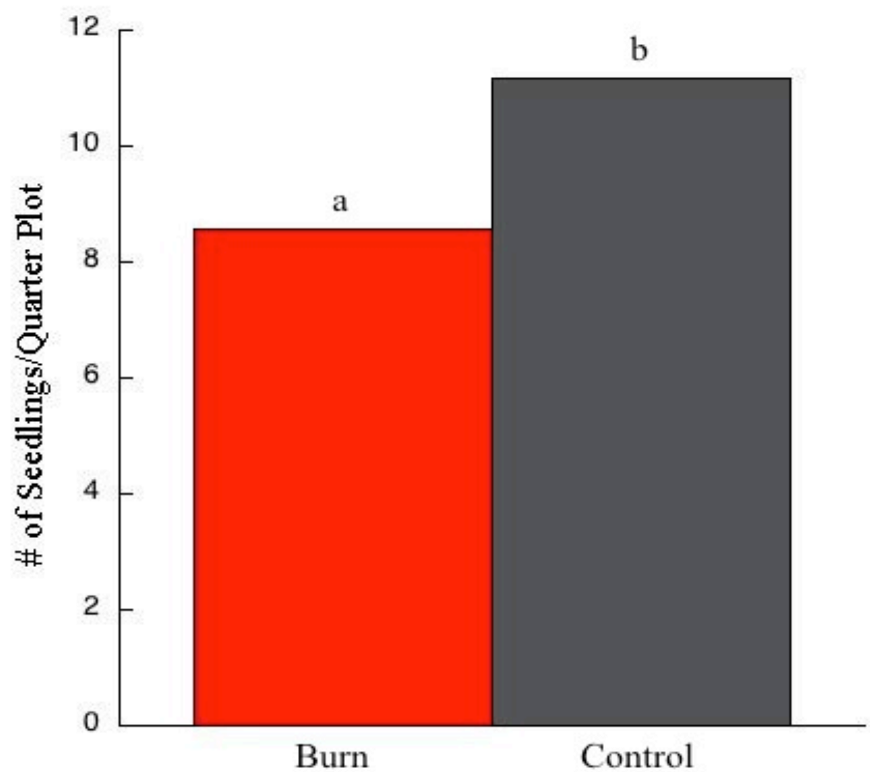

Figure 5. Germination by Treatment – Type I sequential test showed prescribed fire signficantly decreased germination rates in the field ($F_{1,96}$ = 7.54, P = 0.007, R^2 = 0.46).

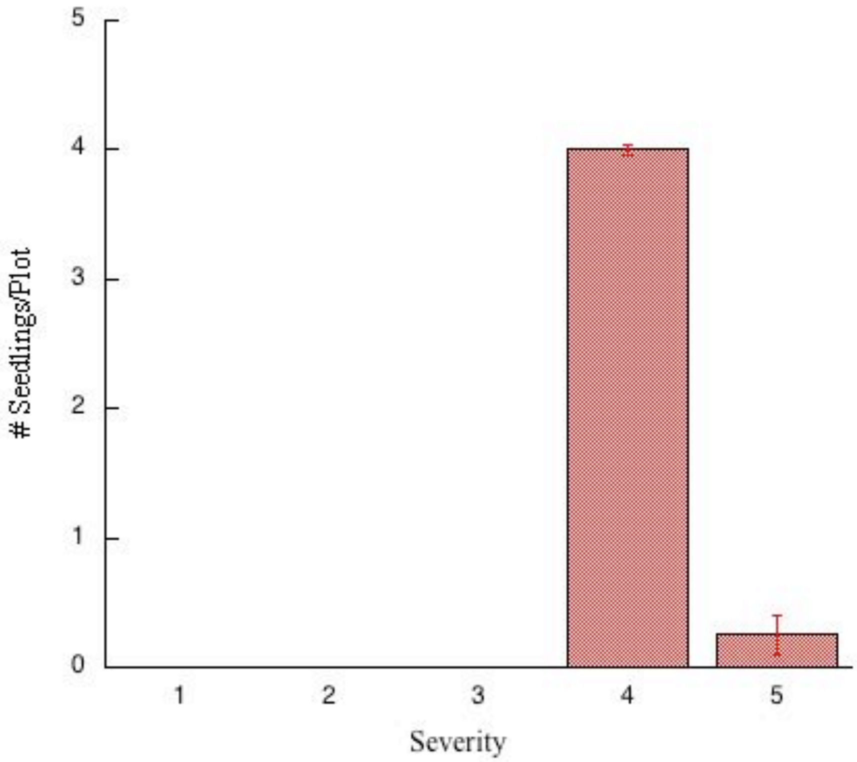

Figure 6. Greenhouse Germination Data – High severity plots had significantly lower germination rates ($F_{1,48}$ = 5.05, P = 0.03, R^2 = 0.13).

Does Prescribed Fire Affect B. sylvaticum *Dispersal?*

We measured dispersal by setting up plots at the start that had <0.5% false brome cover, then tracked *B. sylvaticum* cover over time. Similar to the abundance data and the greenhouse experiment results, we saw that for the dispersal plots, fire severity was the important factor. When we compared fire versus control plots with a MANOVA, there was no significant effect on dispersal ($F_{1,62}$ = 0.66, P = 0.42), but when looking specifically at the severity of treatment, we found it actually did significantly affect dispersal ($F_{4,27}$ = 5.50, P = 0.002) [Table 3 & Fig. 7]. The dispersal plots with the highest severity fires gained fewer plants over time, while the plots with the lowest severity fires gained the most plants over time. Intensity of treatment did not have a significant effect on dispersal ($F_{1,30}$ = 1.96, P = 0.17).

Table 3. Fire Severity Affects *B. sylvaticum* Germination.

Between	**MS**	**F**	**df**	**P**
All	0.81	5.50	4, 27	0.0023*
Intercept	4.42	119.40	1, 27	<.0001*
Severity	0.81	5.50	4, 27	0.0023*
Within				
All	0.49	2.80	8, 52	0.0118*
Time	0.06	0.82	2, 26	0.4525
Time*Severity	0.49	2.80	8, 52	0.0118*

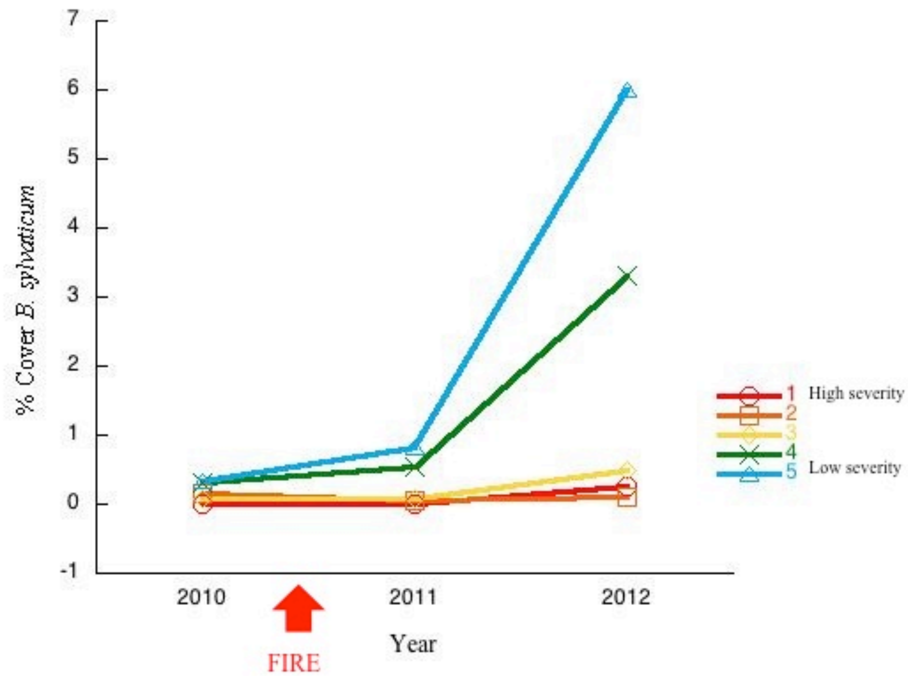

Figure 7. Dispersal – There was a significant effect of severity of treatment on dispersal with low severity plots exhibiting greater levels of colonization ($F_{4,27}$ = 5.50, P = 0.002).

CHAPTER IV

DISCUSSION

Does B. sylvaticum *Affect Prescribed Fire?*

Brachypodium sylvaticum stays green throughout dry summers of the Pacific Northwest. For this reason, we predicted that it could have a dampening effect on fire. While our overall analysis showed no significant affect of treatment overall, and *B. sylvaticum* did not appear to significantly affect fire intensity, we did see an interesting interaction between site and fire severity. The data from Site 1 trended towards *B. sylvaticum* having a significant affect on severity in which plots with high abundances of the grass also exhibited high severity fires, while Site 2 showed a significant opposite affect on fire severity and plots with high abundances had low severity fires [Fig. 3]. One possible explanation for this could be the differences in densities of the grass in each site. Pre-treatment, Site 2 had higher density of *B. sylvaticum* (33±10 vs. 1±0.61/linear m, $P<0.0001$). Perhaps this density of false brome breaches a threshold where the dampening effects of the live, green biomass outweigh the flammability of the senesced thatch from the previous year's growth.

Does Prescribed Fire Affect Abundance of B. sylvaticum*?*

Overall there were no differences in *B. sylvaticum* cover between fire and control plots. However, breaking down the fire treatment into intensity and severity, we did see a significant effect of severity on *B. sylvaticum* cover (low severity = high *B.sylvaticum* cover), but not of intensity, although the data were trending towards significance. It is likely that severity was the more appropriate measure for this analysis since it captures the actual ecosystem effects after fire. Even if a fire burned with high intensity (higher temperatures), the damage to target vegetation could be minimal due to low residence times; the flaming front may have passed so quickly that there was little disturbance to vegetation or soil, for example. Still, my data suggest that the plots experiencing high intensity fires had less of an increase in *B. sylvaticum* abundance than the low intensity plots, even though the p-value was just slightly below significance.

In other studies involving *B. sylvaticum*, fire was observed to significantly reduce *B. sylvaticum* cover or was significantly negatively associated with false brome cover in several studies (DiTomaso et al. 1999, Arévalo et al. 2001, Safaian et al. 2005, DiTomaso et al. 2006). Additionally, *B. sylvaticum* shoot biomass was observed to be significantly lower when grown in high severity burn soil as compared to low severity soil (Hebel et al. 2009). Other researchers have observed a decrease in plant biomass with species other than false brome with increasing burn severity for up to two years after fire treatment (Feller 1996).

For this reason, it may be beneficial to utilize repeated high severity treatments with fire to eradicate, or at least slow, the invasion. However, because high severity prescribed fire could run a greater risk of starting unintentional wildfires, the potential cost in lost timber sales or resources during suppression might not outweigh the benefit for managing agencies. Our fire treatments were set at the end of a very wet and late spring, and perhaps because of this, we were unable to get high severity fire in areas with high *B. sylvaticum* abundance due to the dampening affect from the live green biomass outweighing the flammability of the dead growth from the previous year. If a late summer or fall burn were applied, the results might show that higher severity fires could be attained, thus lowering false brome abundance; however, the risk of spot fires or wildfires would potentially increase as well. Perhaps a series of small area, high severity burns would be more manageable logistically.

Unfortunately, low severity fires conclusively increase *B. sylvaticum* abundance, which suggests that false brome may be an invasive grass species capable of instigating a grass/fire cycle. Areas of high grass abundance burn at lower severity, which results in even higher abundance, and the grass could potentially out compete native species for space and resources. There probably is a threshold level of abundance at which this cycle is set in motion, after which it becomes self-propagating.

Does Prescribed Fire Affect B. sylvaticum *Germination in the Field?*

Prescribed fire signficantly decreased germination rates in the field. When controlling invasive species with fire, it is imperative to kill the target plants before their seeds become viable (DiTomaso et al. 1999) or critically damage the seeds before dispersal can take place (Menke 1992, Allen et al. 1995). Studies of most perennial *Poa* species have found that burning in the mid- to late- spring is most effective (Curtis and Partch 1948, Engle and Bultsma 1984, Becker 1989), the same timing as we used. However, as noted previously, in the Pacific Northwest a fall burn might be more effective, because it would be drier allowing for a more homogenous high severity treatment.

Does Prescribed Fire Affect B. sylvaticum *Germination in the Greenhouse?*

We did not observe any significant effect of treatment (fire vs. control) or fire intensity on germination in the greenhouse, but as observed in the field data, fire severity did significantly decrease false brome germination, primarily in the high severity plots.

Does Prescribed Fire Affect B. sylvaticum *Dispersal?*

Consistent with the abundance and germination data, dispersal plots that experienced the highest severity fires had fewer post-fire *B. sylvaticum* germinants, while the plots with the lowest severity fires showed the highest amounts of germinants. Whether or not this is an indication that dispersal was lower in the high severity fire areas is a bit tricky to assertain. We measured dispersal only indirectly, by tracking infestation over time in burned and unburned plots that prior to fire showed no sign of infestation. While there were no or few plants to start with, this does not mean that there were no seeds present in the seed bank. However, our results are consistent with the grass-fire cycle: low severity fires increase abundance, thereby decreasing the intensity of future fires and continuing the cycle favoring establishment and proliferation of more false brome. High severity fire treatment is the element needed to break the cycle.

Conclusions

Can prescribed fire be used as a method of control for this dangerous invasive? Other studies suggest that if a uniform high severity fire could be achieved and sustained, this method of treatment could be used to control false brome. Unfortunately, fires do not often burn uniformly but instead they usually create mosaics of varying severity across a landscape (Agee 1998), thus rendering this objective challenging. The stakes are high given that our study showed that low severity burns actually increase the germination, apparent dispersal and abundance of this grass. Perhaps if fire treatment is employed repeatedly over time or in conjunction with other methods of eradication (herbicide application, mechanical removal, etc.) effectiveness could be improved (DiTomaso et al.

2006). Most importantly, long-term studies and management plans will be required to monitor success and usefulness of this method.

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