Forage Production Potential in a Ponderosa Pine Stand: Effects of Tree Spacing on Rough Fescue and Understorey Plants after 45 Years

Discussion Paper

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Abstract

We examined the development of understorey forage plant communities in relation to tree density in an experimental ponderosa pine (*Pinus ponderosa*) stand. We used a 45-year-old ponderosa pine spacing trial near Westwold, British Columbia, Canada, with five spacing treatments (1.22, 2.44, 3.66, 4.88, and 6.10 m) to sample understorey biomass and diversity, with a focus on pinegrass (*Calamagrostis rubescens*) and rough fescue (*Festuca campestris*)—two regionally important forage grasses. We predicted that there would be a positive correlation between tree spacing and understorey biomass and a compositional shift from pinegrass to rough fescue under increased tree spacing. We found that rough fescue, the preferred forage species, grew only under tree spacings equal to or greater than 3.66 m, with the greatest biomass at 4.88 and 6.10 m spacings, whereas pinegrass was equally abundant under all spacings. We believe that silvopasture principles could be applied to similar ponderosa pine stands to optimize and maintain both timber and forage productivity.

KEYWORDS: *Pinus ponderosa; Festuca campestris; Calamagrostis rubescens;* stand density; forage; plant biomass; plant community composition; silvopasture

Introduction

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands are often associated with well-developed understorey graminoid communities capable of producing highly palatable forage for wildlife and livestock (Tisdale & McLean 1957; Meidinger & Pojar 1991). Researchers have studied the characteristics of ponderosa pine stands and associated vegetative communities to investigate overstorey–understorey relationships (Pase & Hurd 1958; Moir 1966; Jameson 1967; Uresk & Severson 1989; Naumburg & DeWald 1999; Martens et al. 2000; Peracca & O'Hara 2008; Barbier et al. 2009; Sabo et al. 2009) and to determine the impacts of thinning these stands on understorey communities (McConnell & Smith 1970; Uresk & Severson 1989; Sabo at al. 2009). However, the potential for agroforestry system development and the influence of ponderosa pine on individual understorey species are not well studied (Naumburg & DeWald 1999), and this information is required for managers to make appropriate tree stocking decisions in forests with overlapping timber and forage values. Considering that these ecosystems have limited distribution in British Columbia (BC) (Lloyd et al. 1990), it is important to understand this relationship

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for the purposes of habitat conservation, ecological services, and economic valuation. Furthermore, because graminoid species have different forage values, it is critical to determine overstorey effects on the relative composition and productivity of forage species for utilization in silvopasture systems.

In the absence of fire or other disturbances, competition for light and soil water ultimately influences the growth of ponderosa pine trees and the composition of the understorey community (Fernandez et al. 2008; Gea-Izquierdo et al. 2009). As tree density is reduced, water loss to tree transpiration decreases, soil water increases (Zou et al. 2008), and more water is potentially available for understorey herbaceous vegetation. Furthermore, the reduced canopy structure of lower density stands with gaps between tree crowns increases light availability in the understorey (Lewis 1989) and allows more precipitation to reach the forest floor (Levia & Frost 2006). As tree density alters understorey resource availability, we can expect subsequent changes in community composition of the understorey vegetation.

Rough fescue (*Festuca campestris* Rydb.) is an important rangeland species with high forage value (Johnston et al. 1968). It often dominates high-elevation grasslands (Tisdale 1947) and is prominent in open ponderosa pine and Douglas-fir (*Pseudotsuga menziesii* Mirb.) forests in southern British Columbia (Tisdale & McLean 1957). Pinegrass (*Calamagrostis rubescens* Buckl.) is a common rangeland forage species but becomes unpalatable to livestock by mid-August (McLean 1967; Stout & Brooke 1985). Considering the high forage value of rough fescue and its limited tolerance to grazing, it is important to understand its association with ponderosa pine forests in order to set appropriate forest and range practices and management objectives.

Understanding ponderosa pine and understorey vegetation relationships is important for the application of management regimes that optimize multiple land uses (Pase 1958; Jameson 1967; McConnell & Smith 1970). Plant communities in ponderosa pine–bunchgrass ecosystems can exhibit aspects of both forest and grassland community dynamics (Laughlin et al. 2006). Therefore, the open architecture of ponderosa pine stands is suitable for silvopasture applications where both timber and forage values are managed in an integrated system. Balancing these forest resources requires the co-management of timber production and cattle grazing practices (Wikeem et al. 1993), and monitoring field examples of over- and understorey dynamics provides the insight necessary to evaluate the results of our management and adjust accordingly.

We present the findings of a ponderosa pine tree spacing trial with respect to understorey vegetation characteristics (biomass and species composition) after 45 years of tree growth. This study is unique among ponderosa pine density studies due to its wide range of inter-tree spacing treatments (1.22, 2.44, 3.66, 4.88, and 6.10 m) and the long duration of establishment. Most studies in ponderosa pine stands focus on thinning to decrease tree density and restore open conditions. Although our study lacks the replicated design required to make inferences for ponderosa pine stands throughout the Southern Interior of British Columbia, half-century studies such as this are rare. The long duration of the trial makes this study particularly valuable for understanding plant community shifts between rough fescue and pinegrass, an understudied aspect of ponderosa pine stand dynamics.

We hypothesized that understorey biomass would decrease with increasing tree density (decreasing inter-tree spacing) and that the composition of the plant community would shift towards species tolerant of reduced light and soil water. In our vegetation analysis, we focused on the biomass of rough fescue and pinegrass because of their importance as forage.

Methods

Study site

The study was conducted in a British Columbia Ministry of Forests, Lands and Natural Resource Operations fenced exclosure (ungrazed) built in 1960 near Westwold, British Columbia, Canada (50° 50'45.39" N, 12° 28'47.20" W). The study site is north facing with a slope of 13%. The soils are highly calcareous and derived from till and fluvio-glacial materials with a loamy texture and varied coarse fragment content. Lloyd et al. (1990) describe the soils of the forested ponderosa pine zone as Orthic or Eluviated Eutric Chernozems. Precipitation during the sampling periods of July and August 2006 was lower than the mean monthly precipitation totals over the 20-year period leading up to 2006. The approximately 1.0 ha exclosure was constructed one year after a stand-replacing fire in 1959. The dominant vegetation was likely rough fescue and pinegrass, and two non-native agronomic species, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and smooth brome (*Bromus inermis* Leyss.), were introduced by seeding in 1959 (Illingsworth & Clark 1963). No formal description of the initial plant community was recorded.

The exclosure was planted with ponderosa pine directly following construction in 1960 (Illingsworth & Clark 1963). Figure 1 displays an air photo of the Westwold study site taken in 2007, indicating signs of mortality caused by a bark beetle infestation which occurred after measurements were collected for this study. Five unreplicated square planting densities were applied: 1.22 m (4 ft); 2.44 m (8 ft); 3.66 m (12 ft); 4.88 m (16 ft); and 6.10 m (20 ft). The 1.22, 2.44, 3.66, and 4.88 m spacing stands were each 0.08 ha in size, and the area of the 6.10 m stand was 0.19 ha (Figure 1). Table 1 shows the respective tree density for each spacing treatment at the time of planting. Tree mortality and recruitment were minimal resulting in an even-aged stand within each spacing treatment at the time of measurement in 2006.

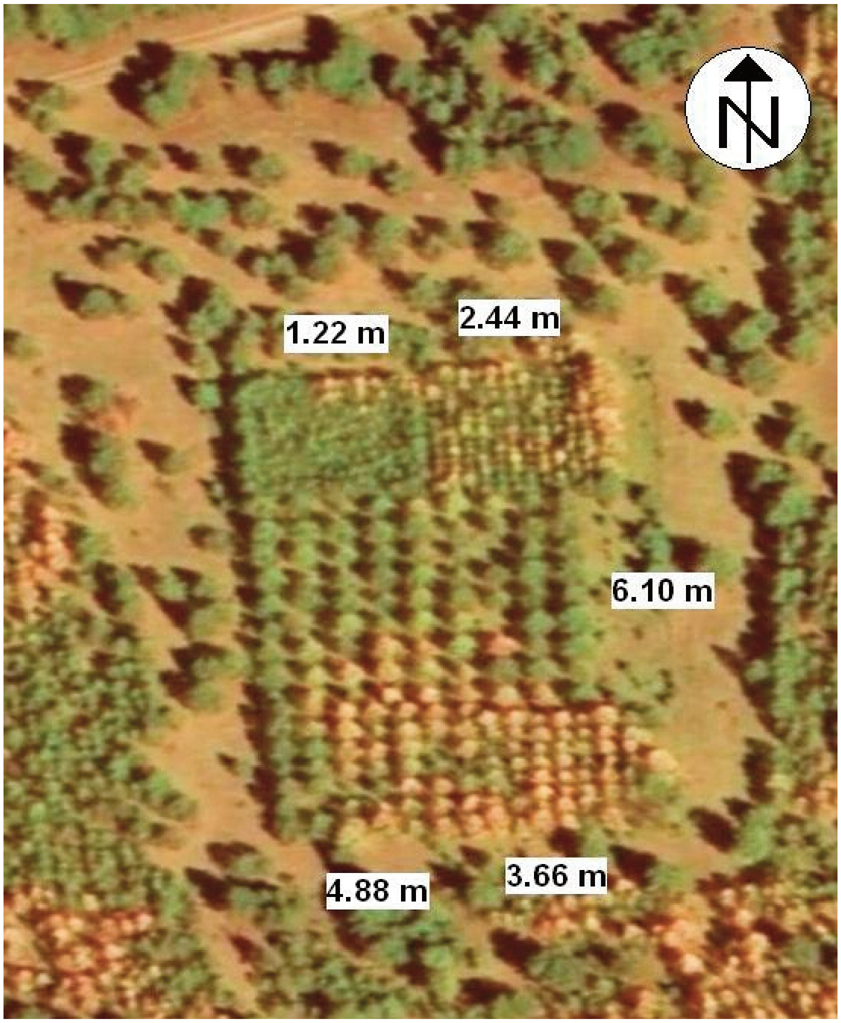

Figure 1: Aerial photograph of Westwold ponderosa pine tree spacing trial study site in 2007 indicating spacing treatments. Tree mortality due to bark beetle activity occurred after measurements were collected in 2006.

Stand characteristics and environmental measurements

On June 1, 2006, height and diameter at breast height (dbh) were measured for each ponderosa pine tree, excluding the outer rows of each spacing treatment to avoid potential edge effects. Three transects were centred in the four central tree rows of each spacing treatment for both environmental and plant biomass measurements. Five soil water and canopy photo sampling points along each transect were taken, centred at equidistant lo-

Table 1: Attributes of spacing treatments at the Westwold ponderosa pine spacing trial: mean tree height and diameter, calculated tree volume per stand, and estimated basal area. Different within-column superscript letters indicate significant differences between height and diameter means among tree spacing treatments based on Tukey's Honestly Significant Difference test. Values in parentheses are standard errors.

Inter-tree spacing (m)	Planted tree density expressed as stems/ha	Trees planted per treatment block	Mean tree height (m)	Mean tree diameter at breast height (cm)	Calculated tree volume (m^3/ha)	Calculated basal area (m^2/ha)
1.22 m	6726	69	4.33 (0.26) a	8.32 (0.84) a	65.24	36.5
2.44 m	1680	42	6.76 (0.65) b	14.80 (1.29) b	74.76	28.9
3.66 m	716	35	12.39 (0.21) c	21.55 (0.65) c	126.95	26.1
4.88 m	420	24	13.24 (0.27) c	23.64 (0.83) c	95.13	18.4
6.10 m	269	20	14.74 (0.49) d	27.58 (1.21) d	91.91	16.1

cations from the four trees surrounding each point for a total of 15 sampling points per spacing treatment. On August 14, 2006, a Nikon D40 Digital SLR camera with a hemispheric fish-eye lens attachment was used to photograph the canopy under a uniformly overcast sky. Photos were analyzed using Gap Light Analyzer software (Simon Fraser University 1999) to quantify crown closure. Soil water content was measured on July 20 and August 19, 2006, under mainly clear skies to a depth of 10 cm using a FieldScout TDR 100 Soil Moisture Meter (Spectrum Technologies Inc.).

Plant biomass sampling

Four 0.25 m^2 plots were systematically located at 2 m intervals along each of the three transects established within each tree spacing treatment for a total of 12 sampling plots per spacing treatment. The three transects were centred in each spacing treatment, and each was centred between tree rows recognizing that this centred transect approach is biased towards forage production. On September 20, 2006, plants in each plot were clipped at soil level, sorted to species, oven-dried at 65°C for at least 48 hours, and weighed.

Data analysis

Data analyses and graphical outputs were completed using R software version 2.10.1 (R Development Core Team 2008). Biomass production data were tested for normality using a Kolmogorov–Smirnov test. Variances within groups were tested for homogeneity using a Fligner–Kileen test (Conover et al. 1981). Means from tree height and dbh measurements were used to estimate the volume of wood per hectare according to the B.C. Ministry of Forests, Lands and Natural Resource Operations' TIPSY program (B.C. Ministry of Forests, Lands and Natural Resource Operations 2001). An analysis of variance (ANOVA) followed by a post-hoc Tukey test was used to test for differences in mean tree height (m), dbh (cm), and percent open sky measured in hemispherical photo analysis among the tree spacing treatments. Soil water for July and August sampling periods were grouped and tested for differences among spacing treatments using a multivariate analysis of variance (MANOVA) with Pillai's trace test. Soil water was then reanalyzed for July and August independently to determine spacing treatment differences using Tukey's Honestly Significant Difference test. Differences in total understorey biomass and biomass of several dominant species under each spacing regime were also tested using an ANOVA, and the correlation between rough fescue and pinegrass biomass production was examined with a linear regression. A permutational MANOVA test of the Bray–Curtis dissimilarity matrix was used to determine multivariate community differences among spacing treatments. We recognize that these analyses are pseudoreplicated at the treatment block level, but we present the data to display the differences among spacing treatments. Differences encountered during all analyses were considered significant at $P \leq 0.05$.

Results

Stand characteristics

Mean tree diameter at breast height and mean tree height were both directly related to inter-tree spacing (Table 1). There was a three-fold difference in both mean diameter and height between the narrowest and widest spacing distances, with the largest difference occurring between the 2.44 and 3.66 m spacings. The estimated volume per tree according to TIPSY and density of trees per hectare were used to calculate the estimated total volume of wood per hectare (Table 1). The intermediate spacing of 3.66 m resulted in the highest volume of wood per hectare, and the highest density of trees at the 1.22 m spacing had the lowest volume of wood per hectare.

Environmental measurements

Tree spacing affected the amount of estimated open sky (Figure 2A). The largest amount of open sky was in the 6.10 m spacing and smallest value in the 2.44 m spacing. A similar trend was observed for soil water (Figure 2B); the highest soil water volume occurred in the 6.10 m spacing and lowest in the 2.44 m spacing for both the July and August measurements.

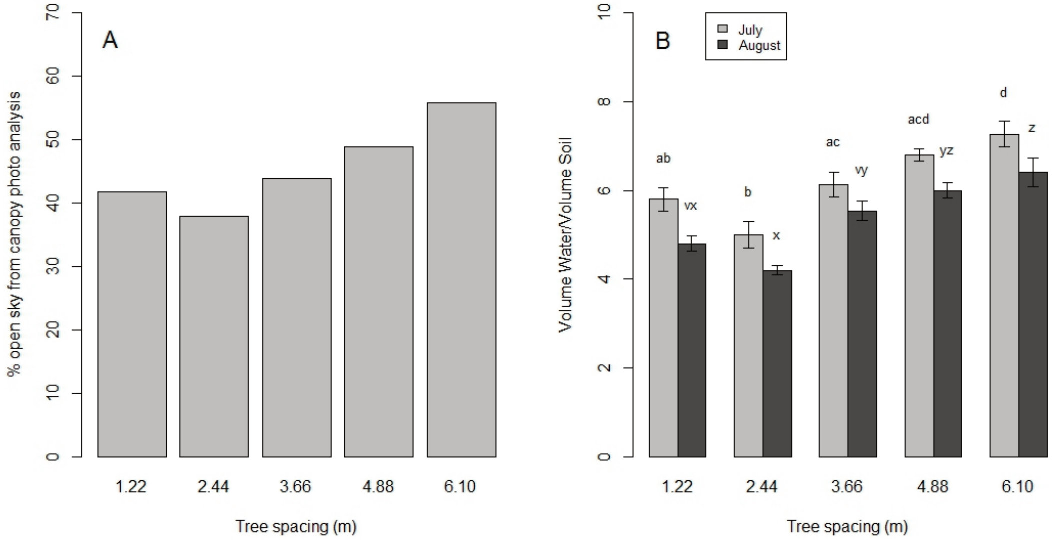

Figure 2: Environmental measurements of (A) % open sky resulting from hemispheric canopy photo analyses and (B) volumetric soil water content for July and August 2006. Unique letters indicate significant differences among spacing regimes (but not between months for soil water measurements) according to Tukey's Honestly Significant Difference test.

Understorey biomass

Total vegetation biomass and total grass biomass were greatest at 4.88 and 6.10 m tree spacings and lowest at 1.22 and 2.44 m spacings (Figure 3A). Tree spacing did not affect total forb or shrub biomass (Table 2). Tree spacing significantly affected rough fescue biomass but had no significant effect on pinegrass biomass. Rough fescue comprised approximately 50% of the total understorey biomass in the 4.88 and 6.10 m spacing regimes while pinegrass comprised the majority of the remaining biomass (Figure 3A). No rough fescue was found in 1.22 and 2.44 m spacings, and rough fescue increased from the 3.66 to 4.88 m spacings (Table 3). Pinegrass biomass was consistently productive across all tree spacing treatments, and there was no significant difference between any of the treatments (Table 3). There was a negative correlation between pinegrass and rough fescue productivity (Figure 3B).

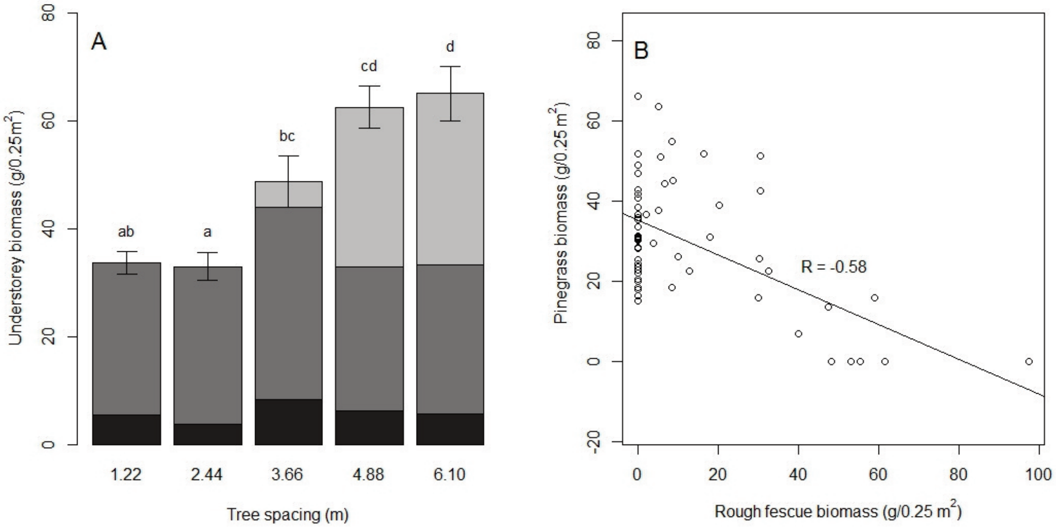

Figure 3: Biomass (A) produced by rough fescue (light grey), pinegrass (dark grey), and remaining understorey vegetation (black); and (B) correlation between biomass (g/0.25 m^2) produced by rough fescue and pinegrass. Unique letters indicate significant differences in total biomass among spacing regimes according to Tukey's Honestly Significant Difference test.

Table 2: Statistical test results for all variables with indications of test employed, results, and significance of differences noted between spacing treatments ($^{\&}$F value approximated for MANOVA tests).

Variable	Test	Sum of Squares	df	Mean Squares	MANOVA Pillai's test	$^{\&}$F Value	Prob.
Tree height (m)	ANOVA	997.09	4	249.274		112.91	<0.001 ***
Tree diameter (cm)	ANOVA	9124.6	4	2281.14		183.64	<0.001 ***
Volumetric soil water content (% vol. water / % vol. soil)	MANOVA		4		0.5484	$^{\&}$6.611	<0.001 ***
Canopy photo analysis (% open sky)	ANOVA	1928.30	4	482.07		59.054	<0.001 ***
Total biomass (g 0.25m^{-2})	ANOVA	11210.3	4	2802.58		15.858	<0.001 ***
Total graminoid biomass (g 0.25m^{-2})	ANOVA	10696.4	4	2674.10		16.872	<0.001 ***
Pinegrass biomass (g 0.25m^{-2})	ANOVA	637.5	4	159.39		0.6127	0.655
Rough fescue biomass (g 0.25m^{-2})	ANOVA	12488	4	3121.88		11.829	<0.001 ***
Total forb biomass (g 0.25m^{-2})	ANOVA	44.334	4	11.084		2.5059	0.052
Total shrub biomass (g 0.25m^{-2})	ANOVA	30.38	4	7.5955		0.9239	0.4568
Species richness per 0.25 m^2 plot	ANOVA	17.933	4	4.4833		1.6699	0.1701
Shannon-Wiener Diversity Index	ANOVA	1.0858	4	0.2714		2.8131	0.0339 *
Community group differences	Perm. MANOVA	3.4174	4	0.8544		$^{\&}$9.0056	0.001 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Table 3: Species and functional group mean biomass (g) per plot harvested under each tree spacing regime. Values in parentheses are standard errors. Different superscript letters within a column indicate significant differences between tree spacing regimes based on Tukey's Honestly Significant Difference test. Values in parentheses are standard errors.

	Spacing (m)				
	1.22	2.44	3.66	4.88	6.10
Grass					
Agropyron cristatum	0.0	0.205	0.0	0.0	0.0
Bromus inermis	2.289	1.618	3.223	1.197	0.150
Carex spp.	0.0	0.0	0.127	0.098	0.222
Calamagrostis rubescens	**28.22 (2.03)**	**29.19 (3.02)**	**35.78 (3.63)**	**26.59 (6.12)**	**27.62 (6.67)**
Elymus trachycaulus	0.053	0.053	0.0	0.0	0.0
Festuca campestris***	**0.0 (0.0) a**	**0.0 (0.0) a**	**4.78 (1.70) a**	**29.70 (6.36) b**	**31.88 (8.16) b**
Koeleria macrantha	0.377	0.005	0.0	0.0	0.128
Poa pratensis	0.0	0.0	0.706	0.098	2.161
Achnatherum richardsonii	0.0	0.0	0.0	0.758	0.744
Total grass biomass***	**30.94 (2.17) a**	**31.07 (2.71) a**	**44.61 (4.10) ab**	**58.45 (3.19) bc**	**62.90 (5.19) c**
Forb					
Achillea millefolium	0.218	0.027	0.646	0.279	0.569
Allium cernuum	0.008	0.0	0.088	0.218	0.0
Antennaria racemosa	0.034	0.005	0.490	0.0	0.0
Aster ciliolatus	0.0	0.0	0.288	0.0	0.0
Aster conspicuus	0.057	0.104	0.493	0.304	0.0
Astragalus spp.	1.683	0.523	0.329	0.482	0.0
Centaurea biebersteinii	0.0	0.0	0.0	0.0	0.083
Erigeron speciosus	0.165	0.053	0.029	0.0	0.0
Fragaria virginiana	0.0	0.0	0.253	0.0	0.068
Galium boreale	0.463	0.006	0.030	0.523	0.415
Medicago lupulina	0.018	0.0	0.0	0.0	0.0
Taraxacum officinale	0.0	0.110	0.0	0.0	0.0
Tragopogon pratensis	0.0	0.0	0.438	0.0	0.0
Viola adunca	0.0	0.0	0.0	0.0	0.004
Total forb biomass ^	**2.65 (0.69) a**	**0.83 (0.26) a**	**3.08 (0.88) a**	**1.81 (0.57) a**	**1.14 (0.45) a**
Shrub					
Arctostaphylos uva-ursi	0.056	1.088	1.084	2.300	1.051
Total shrub biomass	**0.06 (0.06)**	**1.09 (0.63)**	**1.08 (0.57)**	**2.30 1.57)**	**1.051 (0.50)**

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Understorey community composition

Twenty-four understorey plant species were collected and identified from the site (Table 3). Understorey species richness was not affected by tree spacing (Table 2). Species diversity was affected by tree spacing (Table 2) as diversity was highest under the 3.66 m spacing and lowest under the densest and widest spacing regimes (Figure 4B). Plant community composition was significantly different across the tree spacing treatments (Table 2).

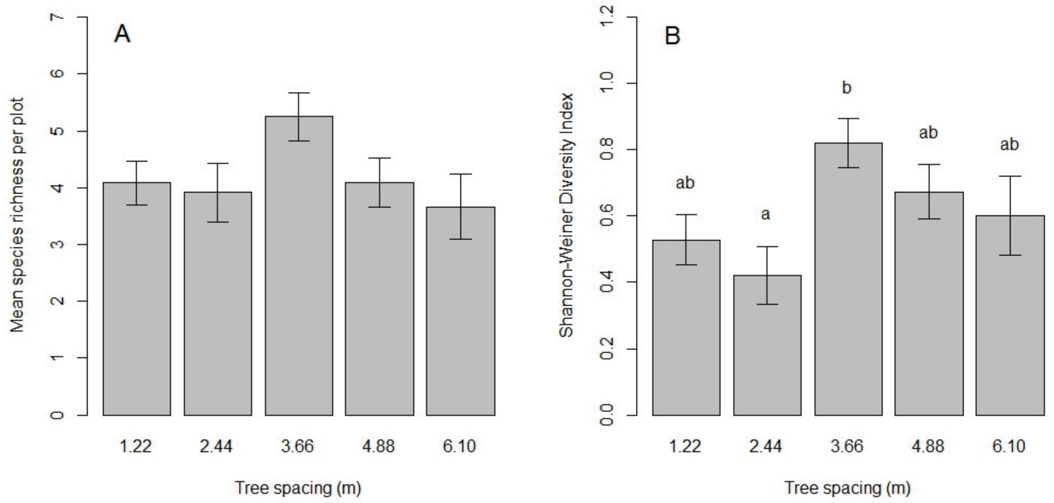

Figure 4: Species richness per plot (A) and Shannon-Wiener Diversity Index values (B) by spacing regime. Unique letters indicate significant differences in total biomass among spacing regimes according to Tukey's Honestly Significant Difference test.

Discussion

We found that the density of a 45-year-old ponderosa pine plantation in the Southern Interior of British Columbia affected some vegetative and abiotic understorey properties and altered forage production potential. The volume of ponderosa pine in different stand densities was consistent with ponderosa pine growth results reported by Gyenge et al. (2010). Stands with higher inter-tree spacing had higher light and soil water levels and higher overall understorey biomass production. Rough fescue was unable to tolerate the low light and low soil water conditions created by the dense tree stands while pinegrass persisted, yet rough fescue dominated the open conditions. Increased tree spacing not only increased forage production but also allowed for a greater proportion of the grass species with higher forage value.

Stand characteristics and effects on understorey resources

Differences in soil water between the spacing regimes were consistent with results noted by Zou et al. (2008) as greater overall soil water use and evapotranspiration by a higher density tree stand limits soil water availability. Soil water content in the upper soil layer represents the shallow soil zone where herbaceous understorey vegetation obtains the majority of its water requirements in spring and autumn (Fernandez et al. 2008). Schulze et al. (1996) found that 50% of the root biomass of dominant Patagonian grasses is in the upper 20 cm of the soil profile. Fernandez et al. (2008) noted proportionally more water use by trees from the upper soil horizon during spring in a moderately dense pine monoculture than a silvopasture with a lower tree density. However, woody trees growing on poor sites have been shown to partition more resources to root production (Kozlowski & Pallardy 2002), thereby increasing below-ground competition for resources. The Ponderosa Pine biogeoclimatic zone is the driest forested zone in British Columbia where soil water availability limits tree growth. Increases in tree density further contribute to soil water extraction adding to the effect of increased proportion of root growth per tree. As well, a longer transpiration period has been found in an open silvopasture stand with fewer signs of water stress when compared to a high density stand, indicating reduced cumulative demand for soil water resulting in a longer growing season (Licata et al. 2008). Higher tree densities are likely to result in less overall available soil water and increased depletion in late spring, leading to longer drought events in the upper soil horizon and shorter periods of productive growing conditions for understorey vegetation.

The relationship between canopy light transmission and stand density is similar to that of soil water content. The hemispherical photos reveal forest canopy characteristics that could further influence water availability in the upper soil layer. Pine species intercept a proportion of total rainfall (Barbier et al. 2009), and from canopy gaps in photos, we speculate that low density treatments could allow more precipitation and ambient sunlight to reach the understorey and increase productivity. Higher ponderosa pine density and canopy cover results in reduced light levels and below-ground resources (Uresk & Severson 1989; Naumburg & Dewald 1999) ultimately influencing understorey plant community composition and reducing total biomass production. However, Gyenge et al. (2002) found increasing evapotranspiration in silvopasture systems as canopy cover decreased. In ponderosa pine stands, silvopasture stand objectives would target a tree density that balances timber and forage productivity while limiting climatic extremes and excessive resource consumption by either the over- or understorey plant community.

Understorey production and composition

We are not aware of any previous study that investigated the relationship between rough fescue and pinegrass under a tree spacing gradient. However, our results are consistent with previous research that shows greater understorey biomass production in well-spaced and thinned stands (Pase & Hurd 1958; Moir 1966; McConnell & Smith 1970) and in ponderosa pine stands elsewhere (Uresk & Severson 1989; Fernandez et al. 2002; Bakker & Moore 2007). Dense crown cover has been shown to reduce range forage values (Dodd et al. 1972), and Lauchlin et al. (2006) recommend that gaps within the forest canopy be maintained to increase herbaceous standing crop. Pase and Hurd (1958) found increases in understorey herbage production following tree thinning to a basal area of 18 m^2 ha^{-1} or less while Uresk and Severson (1989) found similar results at 14 m^2 ha^{-1}, both of which are supported by the calculated basal area estimations in our study (Table 1).

Our study shows that rough fescue, a valuable forage grass, had the greatest biomass in the wide 4.88 and 6.10 m tree spacing treatments and was absent from the 1.22 and 2.44 m spacing treatments. This suggests that maintaining rough fescue in this ponderosa pine stand would require inter-tree distances of at least 3.66 m. Our results also suggest that moderate to wide spacing (lower tree densities) may increase species richness and diversity, although the pattern is not clear. Although tree spacing alters understorey community composition, this pattern is mainly driven by the presence of rough fescue at greater spacing. A plausible speculation for lower diversity towards either tree spacing extreme could be explained by the dominance of ponderosa pine in the high density treatments and competitive exclusion in the plant community by rough fescue in the low density treatments (Grime 1993). The negative correlation between rough fescue and pinegrass production (Figure 3B) provides further support as rough fescue displays the ability to completely exclude pinegrass in several plots. Mesic site conditions are preferred by rough fescue (Hodgkinson & Young 1973) and the reduction in soil water deficits created in the open stands likely promote its dominance, but this effect is confounded by increased understorey light availability with decreased stand density.

We must reiterate that this study occurred within a fenced exclosure, freeing the vegetative understorey from any detrimental effects caused by improper livestock grazing. Considering the high susceptibility of rough fescue to anything but light, infrequent grazing, maintaining this species requires careful management of livestock grazing duration, intensity, and timing. Hodgkinson and Young (1973) recommend that rough fescue be managed as a key species when comprising more than 15% of the total plant composition. To avoid eliminating it altogether, ranchers and range managers must be able to recognize rough fescue and manage livestock to avoid heavy, repeated grazing. Meanwhile, land managers must implement tree stand management practices that provide for conditions conducive to rough fescue persistence.

Conclusion

The Interior Douglas-fir and Ponderosa Pine biogeoclimatic zones encompass most areas in BC where ponderosa pine occurs with at least one, and often both, forage species (Lloyd et al. 1990). Rough fescue is an important forage species for wildlife and livestock because it is highly palatable and capable of maintaining high nutrient value late into the growing season (Hodgkinson & Young 1973). If increased forage production is a major goal in ponderosa pine forests, gaps in the tree canopy are required (Laughlin et al. 2006). Furthermore, high density stands may not be desirable as Peracca and O'Hara (2008) suggest that ponderosa pine may require a larger percentage of live crown than other conifer species. Agroforestry practices have been implemented in pine plantations in the form of silvopastures to integrate timber production with livestock grazing (Lewis 1989; Burner & Brauer 2003). Silvopasture systems manage tree density and distribution in balancing ecological, economic, and social values, including forage production and conservation of important species, within the ecology of the forest. Our study suggests that silvopasture management objectives would require the spacing of ponderosa pine to be 4.88 m or more to maintain rough fescue while providing a productive stand of growing trees. Our results excluded grazing from the system, and further research is warranted on the interacting effects of grazing and growing conditions created by tree stands on forage species.

Although this research lacks the replicated treatments required to make inferences about ponderosa pine stands across B.C., it illustrates the potential variability of understorey plant communities in ponderosa pine forests. The gradient of direct and indirect influence of trees, and potential displacement by dominating rough fescue tussocks, appears to cause a shift in species within the understorey vegetative community. The overlapping habitat preferences and dynamics of a tree crop, in this case ponderosa pine, and desirable understorey vegetation, rough fescue, should be explicitly defined in any forest and/or range management plans prescribed for an area. Failure to set management objectives for forage, as well as stand objectives with both minimum and maximum tree density targets required to maintain forage production, could reduce or eliminate rough fescue from the understorey community. Silvopasture systems offer a solution by managing for the optimal combined potential of multiple resources, and ponderosa pine stands with a rough fescue understorey are ideal candidates.

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Test your Knowledge

How well can you recall the main messages in the preceding article?
Test your knowledge by answering the following questions.

Forage production potential in a ponderosa pine stand: effects of tree spacing on rough fescue and understorey plants after 45 years

1) Increased inter-tree spacing selected for species that had higher forage quality.
   a. True
   b. False

2) Give three management objectives used in the implementation of a silvopasture system.
   a. Microclimate modification to increase productivity
   b. Diversification of forest resources
   c. Conservation of critically important species
   d. All of the above

3) Our study suggested that maintaining rough fescue in the understorey plant community required inter-tree spacing of greater than
   a. 1.22 m
   b. 3.66 m
   c. 6.10 m

ANSWERS: 1=b; 2=d; 3=b