Using Gap Analysis to Assess Vegetation Growth in Jiu Zhai Gou, World Biosphere Preserve Western Szechuan Province, China

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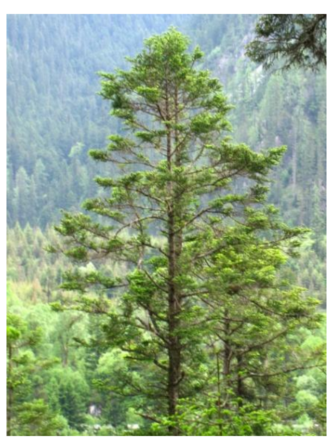
Juizhaigou, World Heritage Biosphere Preserve

Picea



Abies

Betula

ABSTRACT

This research examines the two following questions: Is the secondary canopy of *Betula alba-sinesis* (*Betula*) (a hardwood tree) replacing the historical, forest canopy dominant conifer trees *Abies species (*fir) and *Picea* (spruce) species (sp) in Jui Zhai Gou World Biosphere Preserve (JZG), Szechwan, China? If *Betula* is increasing in proportion to *Abies* and *Picea* sp., what is causing this change in tree demographics? Twenty-six gaps located at elevations greater than 2,900meters (m) were measured for tree species numbers, growth parameters and environmental conditions. Results indicate the numbers of *Betula* have increased at higher elevations compared to their prevalence in the forest prior to 1974. *Abies* species and *Betula* are inversely correlated indicating likely competition between them. *Betula* have a higher maximum rate of photosynthesis than *Abies* or *Picea* sp. and they maintain that maximum rate of photosynthesis over a wider range of Photosynthetically Active Radiation (PAR). Analysis of tree cores indicates that the mean average annual growth of *Betula* trees was significantly greater than that for *Abies* or *Picea* sp. Betula have most significantly increased their numbers in gaps with steep slopes (>30 degrees), small area (< 300 m^2) with thin soil (<3.5 cm depth) or large area (>600 m^2) with deep soil (>12 cm depth). *Abies* and *Picea* sp. establishment is inversely correlated with soil depth and need soil >10 cm depth for dependable establishment of seedlings. *Abies* and *Picea* sp. establish better on slopes of less than 30 degrees. Given JZG climate data indicate a tendency for increased high precipitation events, which increases landslide and tree fall occurrences creating large gaps with shallow soil. Large gaps with thin soil are optimum microhabitate conditions for an increase in *Betula sp*. Further, landslide events decrease soil depth which we found inhibits *Abies* and *Picea* establishment. As bud break on hardwood trees is occurring 10 days earlier than 50 years ago, *Abies* and *Picea* sp. saplings have access to ambient PAR a shorter period of the year before leafed out hardwood trees strongly filter their sunlight. Earlier bud break inhibits the growth of Abies and Picea sp., while *Betula* receives a longer growing season. If these climate trends continue we predict increased competition between *Betula* and historically dominant *Abies* and *Picea* species, with increased numbers of *Betula* particularly at high elevations or on steep slopes. It is recommended biogeochemical studies be done on water runoff from *Betula* litter in areas where Betula has become a significant part of the mature montane forest to discern its effects on water quality and mineral characteristics in JZG lakes.

INTRODUCTION:

Jui zhai gou (JZG) is a located in the North-Western Min Shan mountain range at 103◦46′–104◦50′E, 32◦55′–33◦20′N in Western Szechuan Province, China. Jiu Zhai Gou is a Y-shaped valley descending from south to north, covering an area of 720 km^2 and reaching elevations from 2,000m to 4,500m. Prior to becoming a national park in 1980, parts of Jui Zhai Gou were used by local villagers for pastural grazing and farming, and from 1975 to 1978 areas were used for commercial timber production. Commercial logging led to portions of the park being clear-cut or selectively cut. JZG was declared a World Heritage Site in 1992 and a World Biosphere Preserve in 1997. (Winkler 1998)

Today, the park is a major tourist attraction and a national treasure. Jui Zhai Gou is famous for the 101 turquoise lakes featured through out the valley. The most scenic geologic features of the park are formed by karst and travertine formations. Travertine is a sedimentary rock formed by calcium carbonate precipitation. The calcium deposits interact with algae, and minerals in the water to give the lakes their colorful appearance.

Although Jiu Zhai Gou is a temperate montane forest, it is highly influenced by subtropical storms. The summer months are dominated by monsoons, which contribute a majority of the annual precipitation. In the past 40 years heavy precipitation events have increased (Li Gou, Academica Sinica 2010, Pers. Comm.) Snow falls from October to February at all elevations in the park. Yearly, average daily temperatures range from -3.7ºC to 16.8ºC. (Winkler 1998). Temperatures at high elevation have been warmer earlier in the year resulting in bud break of hardwood tree species (like *Betula*) being approximately 10 days earlier than was the case 50 years ago (Yuwen Tsai, 2010, JZG Director, Personal Communication).

Jui Zhai Gou has an extremely diverse floral community which contains over 2,576 plant species, 150 of which are tree species (Winkler 1998). Amongst the undergrowth, smaller trees, shrubs and herbs such as *Acer* sp. (maples) rhododendron, bamboo, wild roses, and orchids can be found.

Purpose

Recently, park personnel became concerned that the hardwood species - particularly *Betula* species- appeared to becoming more common at high elevations. Historically at elevations greater than 2900m, the primary canopy was dominated by *Abies* species*,* and *Picea* species*,* and only the lower secondary canopy contained, red-barked, *Betula* (Winkler

1998). Betula species established\due to disturbances to the Abies forests at 3100-3400 m (Danwei 2001). Old photographs of the park show distribution of hardwoods to be primarily concentrated at medium (2900-2600m) and lower (below 2600m) elevations. If the hardwood species are becoming more competitive and displacing conifers, there are concerns that the litter from the hardwoods will have a lower pH causing a change in mineral leaching patterns, which could have a negative effect on the aesthetics of the famous lakes.

Under the null hypothesis that there is no change in the proportion of hardwood species to conifer species, we conducted a gap analysis at elevations greater than 2,900m. Gaps are breaks in the forest canopy caused by tree fall, tree death, landslides and logging activities. Gaps in the canopy allow increased sunlight onto the forest floor, and increase tree and shrub growth below. Gap dynamics theory states that, in the occurrence of canopy disturbance, the increased amount of light on the forest floor will allow shade-intolerant species to maintain their population by growing in the gap (Yamamoto 2000; Bartimucci et al 2002). Typically those shade intolerant species die out of the forest community as the gap closes over time from growth of trees in and around the gap. In Jui Zhai Gou, *Betula* is a competitive shade-intolerant species that can reach canopy heights and when in full leaf, can deeply shade saplings and seedlings of other species. Typically this species starts to die out when most gap trees reach a diameter of 25 cm and a height of 24 m or more. The very common, *Abies faxiona*, and less frequent but still common *Picea purpurea* plus a few less common *Abies* and *Picea* species and *Sabina* species (all conifers) historically have made up the mature montane forest community in JZG.

Global climate change models have shown forest dynamics and tree distribution to be highly sensitive to global climate changes (Changfu Huo, Genwei Cheng, Xuyang Lu, and Jihui Fan 2010). An understanding of each species light sensitivity is important in determining whether climate change may be affecting the forest dynamics of Jui Zhai Gou. Consequently, In addition to a gap analysis, light response curves were run on saplings of each species to determine their light sensitivity in relation to photosynthesis rates. Light response curves on the various species helps determine the environmental conditions at which they are most productive.

METHODS

Surveys were done of gaps ranging from 76.36 to 1680.96 m² at elevations greater than 2,900 m. Gaps were chosen above 2,900m because our tree species of primary concern, *Abies faxoniana*, and *Picea purpurea* do not grow below 2,900m. To be considered a gap, the area needed to be greater than $50m^2$ and have young trees within it which were no taller than 2/3 the height of the surrounding canopy trees. To be measured, a gap needed to be safely accessible to researchers, therefore it could not be located under a landslide area, or on a slope greater than 45 degrees.

Gaps were surveyed for multiple aspects which could be effecting the reproduction and growth of trees (Taylor and Qin, 1992). The age and the size of gap, canopy composition, soil depth and type, aspect, degree of slope, ground cover, and amount of photosynthetically active radiation (PAR) were measured. The size of the gap was determined by measuring the perimeter around the surrounding canopy trees, and measuring the vertical and horizontal diameters of the gap using metric measuring tapes (Huth and Wagner, 2006). The data obtained from the perimeter and diameters was then used in area formulas based on the shape of the gap and used to calculate the area of the gap. The composition of the stand surrounding the gap was assessed for the percentage of hardwood and conifer species in the canopy. Gaps with a surrounding stand composed of >80% either conifers or hardwoods were considered dominated by that type of tree. Stands with compositions consisting of less than 80% of hardwoods or conifers were considered a mixed stand. Soil depth was obtained using a measuring rod. The measuring rod was inserted into the soil until insertion became difficult, the remaining length of the rod was measured and the length was subtracted from the total length of the measuring rod. This was done four times for each measurement. The aspect of the slope was obtained using a Sunnto MB6 Global Compass. The dominant vegetation, ground cover of the gap was assessed in categories of 1/3, 2/3, and 3/3 of the total gap vegetation at ground level. The age of the gap was obtained by observing the decomposition rates of the felled trees which had caused the gap and coring fallen trees. In some cases, the gap was caused by more than one tree fall and then the age of the gap was estimated within a range. The average amount of photosynthetically active radiation (PAR) available in each gap was measured using a Decagon Ceptometer.

Within each gap, saplings and canopy trees had their species, height and DBH (diameter at 1.1 m) recorded, and seedlings (<1 cm stem diameter, < 1 m height) were counted. This study focused on *Picea*, *Abies*, and *Betula* species. All seedlings less than one meter in height, and with a DBH less than one centimeter were counted for each species. Canopy trees and saplings with DBH>1 cm were individually measured for their height and DBH. Height was estimated using a 120m Laser Hypsometer Rangefinder, and a meter stick.

The DBH of large trees was assessed using a 50cm tree caliper and the DBH of saplings was assessed using a 10 cm plant caliper.

In an effort to determine the mean annual growth of each tree species each year, >80 trees in high elevation gaps were cored. Coring was done using 50 cm Hagloff tree core tool and tree caliper. The DBH of each tree was measured using the caliper, the coring tool was marked at ½ the diameter of the tree. Marking the coring tool ensured that the center of the tree would be reached and any excess damage to the tree would be avoided. Once all of the cores were collected, the rings of each core were counted using hand lenses and microscopes.

To determine the humidity and sunlight conditions at which each species is most successful, light response curves were measured for twelve, 50 cm tall seedlings, (4 *Betula albo-sinensis*, 4 *Picea purpurea* and 4 *Abies faxonian)a*. The juvenile trees were collected at high elevation locations in Jui Zhai Gou, and transported back to a laboratory. In the laboratory, they were held under temperatures ranging from 18 to 21degrees C for 3 weeks with ambient light coming from a window with southwest aspect. Once the seedlings had become acclimated to the laboratory environment and recovered from the shock of transport, light response curves were conducted using a LICOR 6400 Photosynthesis analyser. Light response curves were conducted on each species at a range of PAR10 to PAR1500 sunlight ranges.

RESULTS

A Linear Regression analysis was conducted (statistical analysis was done with much assistance and advice from Dr. Yu Zhan, and Dr. Ming Hua Zhang, September 2010, UC Davis) on the effects of area and soil depth on *Betula*. The percentage of Betulas was calculated by dividing the total number of Betulas in one gap by the total number of Betulas, Abies and Picea in the same gap. A linear regression model was formulated using the following equation: b_pct~area+soil_depth+area*soil depth. The linear regression model showed that area, soil depth, and the interactions are all statistically significant.

To test for normality of the distributed population a Shaprio-Wilks test was conducted, using the equation

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

The data was divided into two groups based on the sequence of the predicted Y. The first group contained 13 data points and the second contained 12 data points. The p-value of the test is .1541, a number larger then .05, which confirms that the assumptions of the linear model were met. The predicted Y vs. residual confirmed the normality inference.

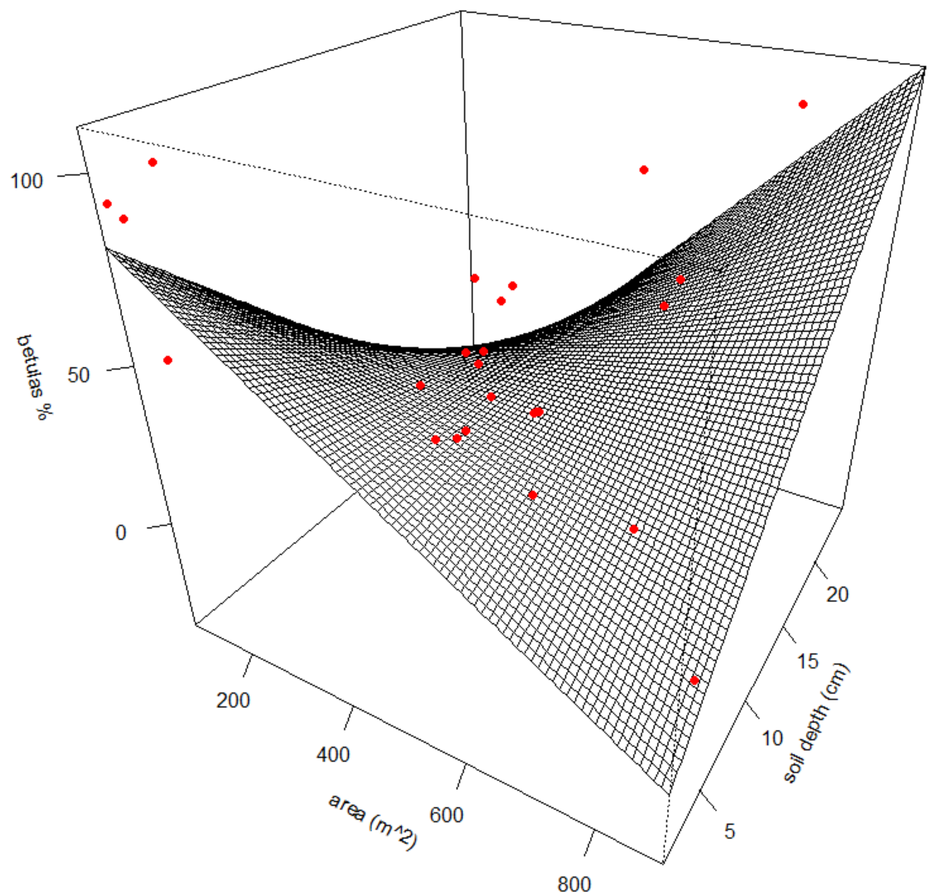
Levene's test for homogeneity of variance was conducted on the data to confirm that the population variances are equal.

$$W = \frac{(N-k)}{(k-1)} \frac{\sum_{i=1}^{k} N_i (Z_{i\cdot} - Z_{\cdot\cdot})^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} (Z_{ij} - Z_{i\cdot})^2},$$

The test resulted in a p-value greater than .05, showing that the homogeneity of variance assumption is met.

Interpretation: This regression shows thin soil in small area gaps and thick soils in large area gaps resulted in a higher % of *Betulas* (see Figure 1).

Figure 1 A 3-D Plot of the Effect of Area and Soil Depth on *Betula*



Correlation analysis

Correlation analysis was done between all environmental factors.

Table 1. Correlation Analysis Results

The colored means are significant p<0.05; Spearman-rank correlation test):

	Hardwood	Picea	Abies	Betula	slope	elev	perimeter	area_m	soil_depth
Conifer	0.25	0.79	0.91	-0.44	-0.71	-0.32	0.19	0.29	0.41
Hardwood		0.20	0.26	0.16	-0.05	0.32	0.26	0.35	0.14
Picea			0.63	-0.21	-0.52	-0.38	0.37	0.49	0.20
Abies				-0.42	-0.64	-0.31	0.18	0.24	0.33
Betula					0.54	0.22	0.12	0.00	-0.17
Slope						0.53	0.25	0.10	-0.16
elev							0.19	0.06	0.34
perimeter								0.92	0.07
area_m									0.04

Note: Conifer and hardwood databases contained all species of conifers and all of hardwoods not just the dominant species.

Interpretations from Table 1:

- *Picea*, *Abies*, and conifer_all are significantly positively correlated with each other. This indicates *Picea* and *Abies* are representative of conifers.
- *Betula* is signicantly negatively correlated with Conifer and *Abies*.
- **Slope** is significantly negatively correlated with Conifers, *Picea*, and *Abies*, while significantly positively correlated with *Betula*. This indicates *Betula* is better adapted to steeper slopes, while conifers are better adapted to gentler slopes above 2900m.
- **Area** is significantly positive to *Picea*. This indicates *Picea* is better adapted to larger gap areas.
- **Soil depth** is significantly positively correlated with Conifers. This indicates conifers are better adapted to deeper soil depth.
- **Elevation** is significantly positively correlated with slope. This indicates gaps at higher elevation tend to be steeper.
- **Area** is significantly positively correlated with perimeter. Indicating both are indicative of gap size.

Table 2. Correlation with percentages of each species (p,0.05, Spearman-rank Correlation test)

	Abies	Betula	slope	elev	perimeter	area_m	soil_depth
Picea	0.09	-0.38	-0.18	-0.25	0.08	0.17	-0.06
Abies		-0.90	-0.61	-0.22	-0.07	0.00	0.35
Betula			0.62	0.35	0.03	-0.09	-0.25

Interpretations from Table 2:

- *Abies* is significantly negatively correlated with *Betula*. It indicates Abies and Betula likely have competitive relationship.

- **slope** is significantly positively correlated with *Betula* and negatively correlated with *Abies.* It indicates slope may be a limiting factor for *Abies*, and *Betula* is more competent in steeper areas.

Graphs of Means

Means from *Betula*, *Abies* and *Picea*, DBH size categories in gaps with various environmental conditions and areas are shown in Graphs 2a-2d below which were tested by a nested ANOVA.

Figure 2a indicates the seedlings of *Abies* require medium to deep soil to germinate, whereas *Betula* can germinate in thin soils but prefer thick soil for germination given adequate light.

Figure 2 a

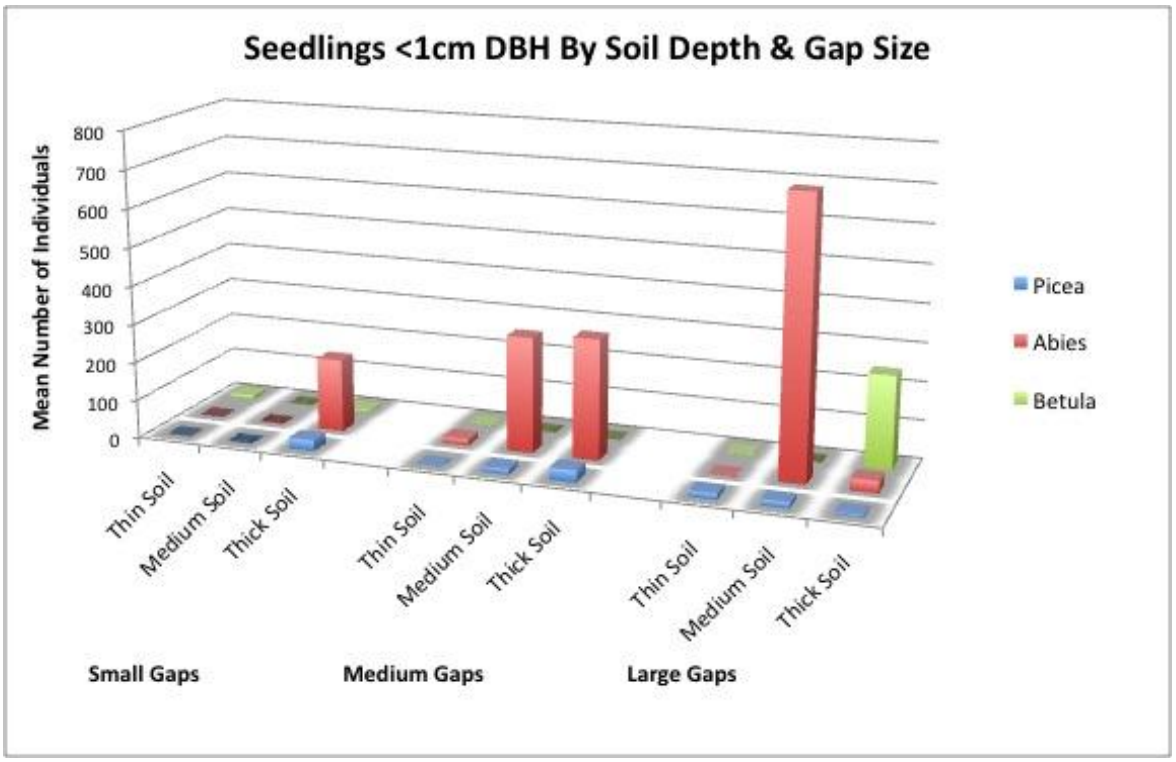


Figure 2b represents all saplings with DBH <10cm. Establishment of *Abies* saplings requires medium or deep (thick) soil, regardless of gap size. Whereas *Betula* can establish in thin or deep soil if it has adequate light. Picea establishes only small numbers of saplings in gaps regardless of the gap size.

Figure 2b.

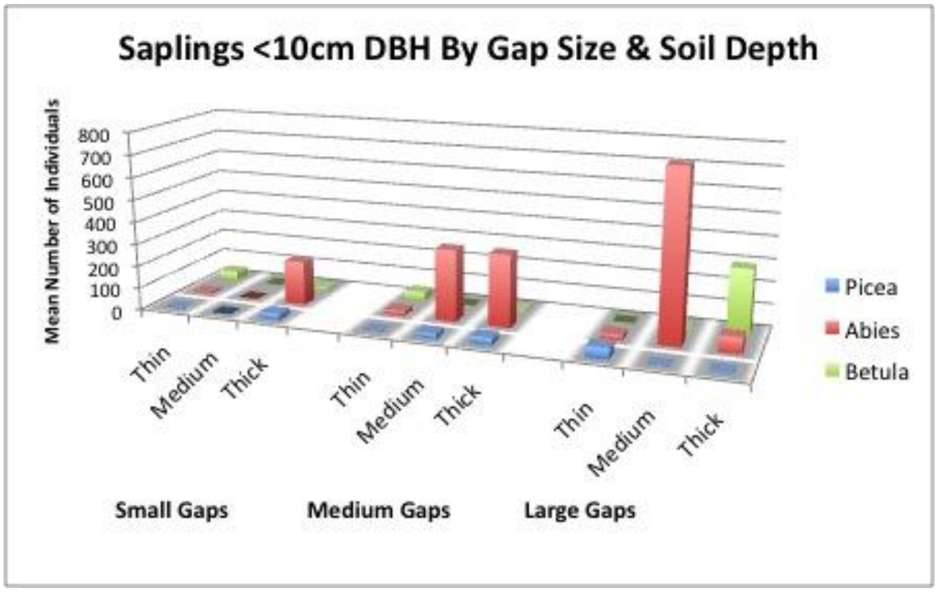


Figure 2c displays mature saplings. The figure indicates that *Betulas* have the greatest success in large gaps, however their saplings can establish in thin soil as well. While it may appear as though Picea and Abies are establishing in thin soil, they have limited capacity to do so and their numbers are significantly lower in medium and large gaps than *Betulas*.

Figure 2c

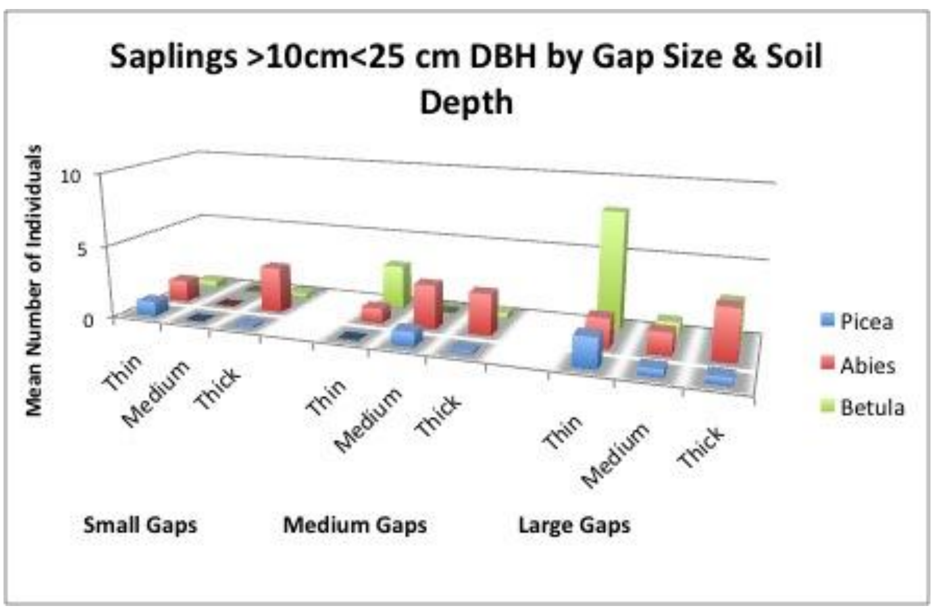
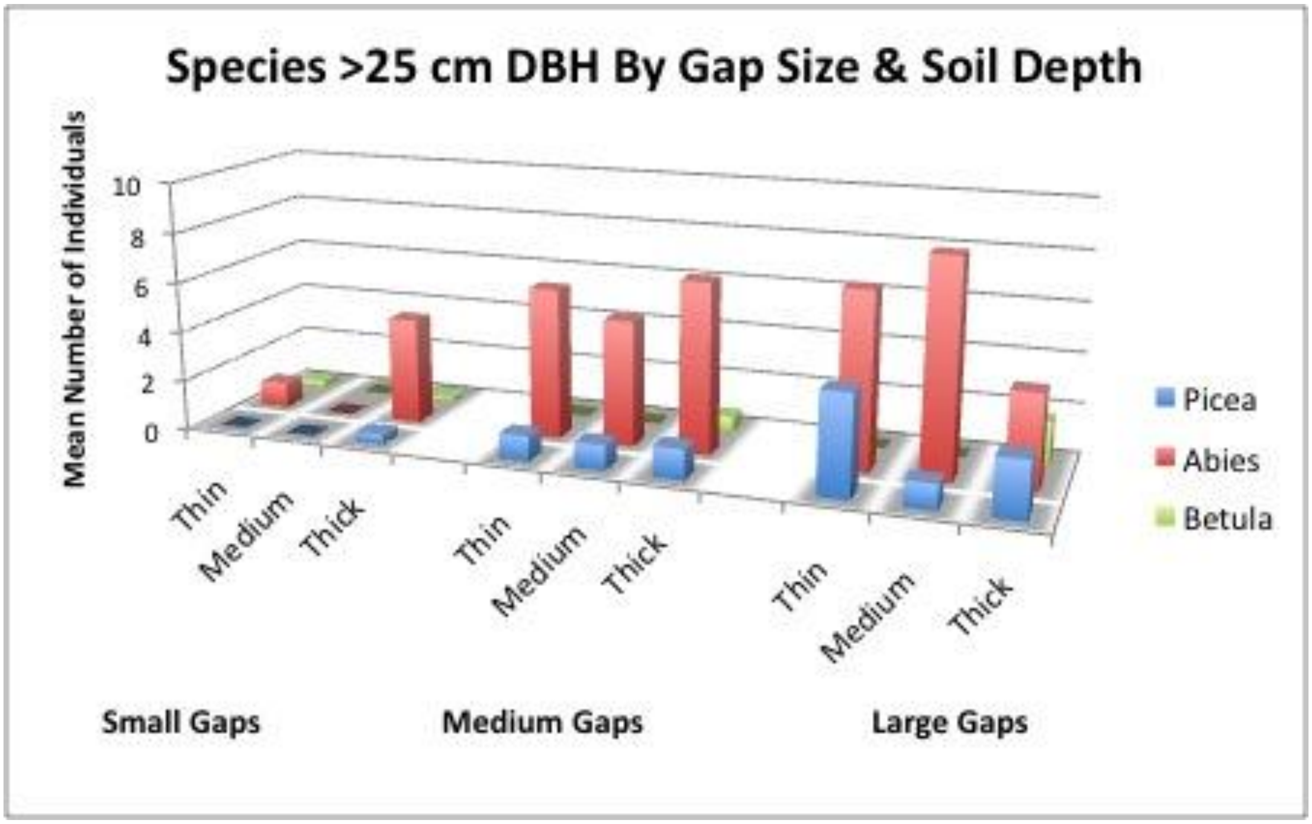


Figure 2d shows Mature trees with DBH greater than 25cm. The graph shows *Betula* are still very much part of the maturing, late gap succession forest community. Typically, by >25cm DBH, about 40 years old, the *Betulas* would have disappeared from the forest community, shaded out by taller *Abies* and *Piceas*. However, *Betulas* remain part of the community in small gaps with thin soil, and especially in large gaps with thick soil and claim a share of the canopy.

Figure 2d



Tree Coring, average annual growth by species

Means of annual rate of growth in diameter for *Betula*, *Abies*, and *Picea* were compared using an ANOVA test. The results in Figure3 revealed the mean annual rate of growth for Betula .43 cm/yr was significantly higher than the Abies.34cm/yr, and Picea .22 cm/yr (Dunnett Test, the F=7.63, the P <.001).

Figure 3.

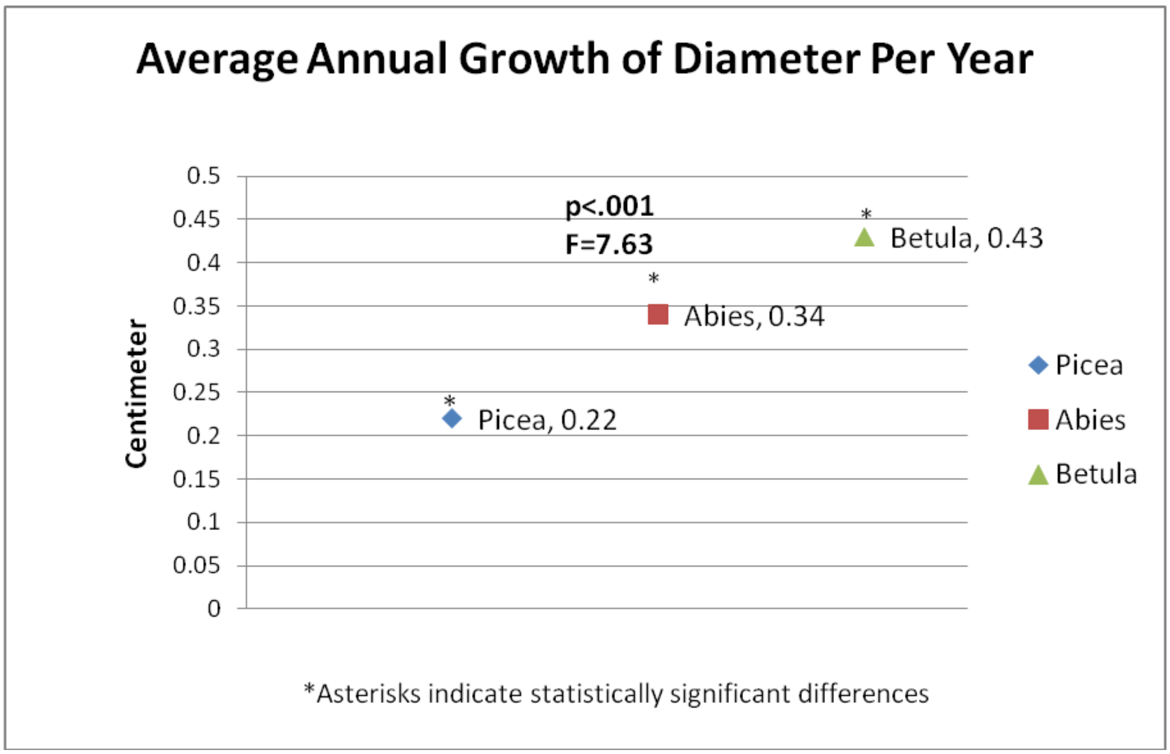
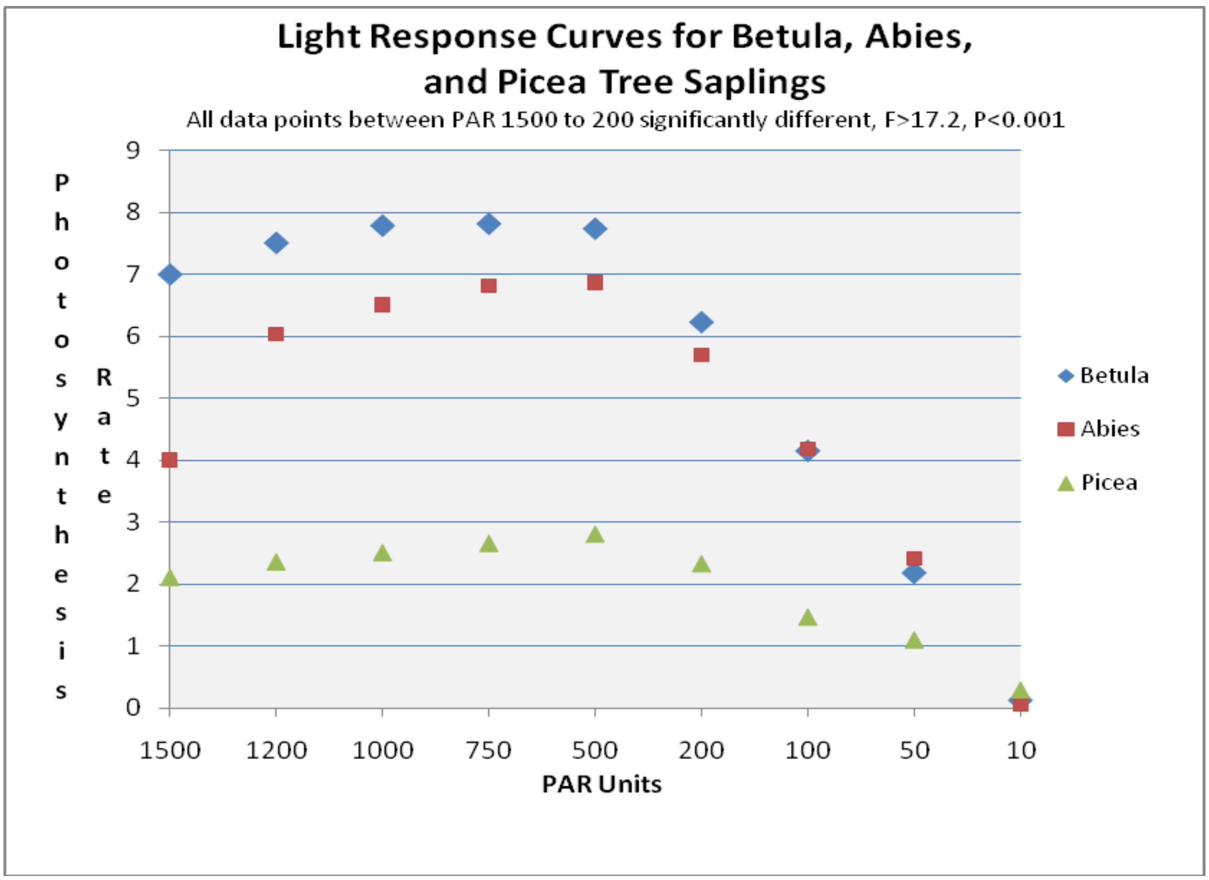


Figure 4. shows the light response curves measured using the LICOR 6400. Figure 4. illustrates that *Betula* have a much higher photosynthetic rate than *Abies* and *Picea* at PAR's greater than 500 units. At 200 units, *Betulas*'s rate is slightly better than *Abies*, athough the difference is not statistically significant. *Betula* not only have a higher maximum rate of photosynthesis (7.9) than *Abies* (6.9) or *Picea (2.9)* sp., *Betula* maintain that maximum rate of photosynthesis over a wider range of PAR, 1200-500 PAR. Picea have the lowest photosynthetic rate at all PAR units, failing to attain a photosynthetic rate greater than 3. Photosynthetic rates for *Picea* and *Abies* actually decrease above PAR 500.

Figure 4.



CONCLUSIONS

Light response curves show Betula is a heliophyte species that benefits from increased access to sunlight. Sunlight is most available in either large forest gaps or small gaps containing thin soil in which the Betula encounter little to no competition from the Abies and Picea. This is consistent with Taylor and Qin's 1992 observation that Betula is more gap dependent for regeneration than Abies sp. De Romer et al 2007 found in a study of southern boreal forests of eastern Canada, tree species requiring relatively large amounts of sunlight become more numerous when larger gaps are present. This is particularly relevant considering JZG's history of clear cutting and pastoral grazing, which may have initially enabled Betulas to increase in number.

Dan Wei Ma's 2001 study in JZG, resulted in his prediction that Betula at low and medium elevations, below 2800 m, will be squeezed out of the forest community as the gaps close. However, our study done in communities over 2900m contradicts his findings in several ways.

1. The tree cores revealed Betula's mean annual growth is twice that of Picea and 25% greater than Abies species for high elevation trees.
2. Betula's greater mean annual growth rate at high elevation indicates that when conditions permit, juvenile Betula can outgrow and overtop juvenile Abies and Picea, preventing through shading their access to adequate levels of PAR.
3. *Betula* have increased their numbers in some types of high elevation gaps and are no longer being shaded out of the forest community as the gaps age and close. *Betula* most significantly increased their numbers in gaps with steep slopes (>30 degrees), small areas(<300 sq m) with thin soil (<3.5 cm depth), or large areas (>600 m^2.) with deep soil (>12 cm depth). In gaps with these conditions, *Betula* can germinate, establish and mature into canopy trees that share the canopy with *Abies* and *Picea* and in some areas become the dominant species.
4. *Abies* and *Picea* sp. establishment is inversely correlated with soil depth and they need soil >10 cm depth for their seedlings to establish dependably as saplings. While *Betula* establish better in deep soil, they can survive in thin soil as well. Since thin soil is common on steep slopes this is another indicator that *Betula* are well adapted to growth on high elevation steep slopes.

5. The JZG climate’s tendency for increased high precipitation events increases land slide and tree fall occurrences and leads to larger gap sizes and less soil depths. This infers the optimum microhabitate conditions for *Betula* are increasing at high elevation. Further, landslide events decrease soil depth, which we found inhibits *Abies* and *Picea* establishment. Earlier bud break is causing *Abies* and *Picea* sp. saplings to have access to ambient PAR a shorter period of the year, further inhibiting their growth.

While bud break on *Betula* is occurring earlier and receiving a longer growing season. It is true even at high elevation in JZG, historically, as gaps closed in the course of succession, hardwoods, including *Betula*, were shaded and displaced (Winkler 1992). However this study found under current environmental conditions, *Betula*’ s increased growth and competitiveness at high elevations especially on steep slopes, with thin soils or in large area gaps which allow much light availability for many years during which the *Betula* reach mature canopy height, is inhibiting the normal course of succession in this montane forest. . If these climate trends continue, we predict increased competition between *Betula* and the historically dominant *Abies* and an increase in the numbers of *Betula* at high elevations or on steep slopes.

Recommendations for future research:

It is recommended biogeochemical studies be done on water runoff from *Betula* litter in areas where *Betula* has become a significant part of the mature montane forest to discern its effects on water quality and mineral characteristics that could impact the water characteristics in JZG lakes, since it appears *Betula* under current conditions is now a more important member of this forest community than it was in the past.

One finding difficult to explain is that *Picea* appears to do better in large gaps, this maybe due to greater heterogeneity of microhabitats existing in large area gaps. Ban et al 1998 found in his study of old growth boreal forests in northeastern China, large area gaps increased the diversity of stand structure. *Picea* do not establish in large numbers in gaps of any size. However, in a small percentage microsites *Picea* are successful, more microsites may improve the odds of some of them having conditions suitable for *Picea* growth.

Another question that arises from this research is what makes the *Betula* well adapted to steep slopes? Further research is recommended on root/ shoot ratios of *Betula*, *Abies* and *Picea* since root/shoot ratios directly effect both anchorage and ability to obtain nutrients.

A close examination should be done on the annual rings of cored trees since this should reveal during which periods these three species grew best. The tree core information can then be correlated with historical weather data, and give insight into whether *Betula* or *Abies* will be the most competitive species in the future in high elevation JZG forests.

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