Forest Regeneration Under Scotch Broom Control

Annual Report October 2008

Submitted to Fort Lewis and The Nature Conservancy

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TABLE OF CONTENTS

Introduction

The pest plant Scotch broom (*Cytisus scoparius*) is hindering effective reforestation at Fort Lewis, resulting in both a loss of land available for military training as well as a loss of native forest habitat for native plants and animals. In prairie areas of Fort Lewis and nearby public lands, *Cytisus* control has been a central feature of prairie restoration and management for decades, and best management practices are well developed for that environment (e.g. Dunn 2002). However, the forestry context presents challenges as well as opportunities for *Cytisus* control. For example, there may be fewer control options available in reforestation compared to prairie restoration. On the other hand, a successful endpoint in reforestation is definable: at some point tree seedlings should overtop and shade out the *Cytisus* layer.

Our primary objectives are to examine the control strategies that are unique to reforestation. In particular, the use of fire is not a viable control option in reforestation, especially after tree seedlings have been planted in. Alternatives such as soil scarification and herbicides are more viable, yet it is currently unknown whether, or to what extent, repeated treatments are more efficient than single treatments. Another gap in our knowledge involves understanding whether pre-treating sites before planting is more efficient or cost-effective than treating or controlling broom following planting of tree seedlings. Our secondary objectives include understanding indirect effects of control strategies, such as broom mulch left on-site following biomass removal. The effects of broom mulch are currently not well-known: mulch has high nitrogen concentrations and may provide a fertilization effect for tree seedlings, but *Cytisus* also produces secondary defense compounds which may present an inhibitory effect in the mulch. Where trees are planted, relative to other mature trees or the edge of intact forest, is also a potentially important factor that is part of our suite of objectives.

This document reports on the first year's activities of an overarching research collaboration between personnel at the University of California Santa Cruz and at Fort Lewis. Key research questions for this phase of the research project include:

- What are the costs and benefits of an extended pre-treatment phase, including two or even three years of soil scarification and control of small *Cytisus* plants before planting?

- How much treatment is necessary after Douglas fir saplings are planted?

- Will herbicides need to play a role in effective *Cytisus* control? What is the risk to Douglas fir sapling survival and growth?

- Does planting Douglas fir saplings near edges or near large, established trees increase their successful establishment?

This report lays out the rationale and experimental design for two large-scale experiments that address the first three questions, and one pilot experiment that addresses the final question.

Response to Broom Control: Randomized Field Experiments

Two experiments, coordinated but designed to be analyzed separately, are being used to evaluate different treatment options for controlling Scotch broom either before or after planting Douglas fir seedlings. The experiments address pre-planting control strategies (the "PRE" experiment) separately from post-planting control strategies (the "POST" experiment). Treatments for the PRE experiment are outlined in Table 1 and focus on evaluating the effects of stimulating germination of broom through soil disturbance, and the effects of multiple years of broom control before planting of Douglas fir seedlings, with no follow-up control after planting.

Table 1. Treatments: PRE-Planting Experiment. For the pre-planting experiment, the following treatments were planned. Two of these (A and B) were planted in Spring 2008 and will need to be re-planted in Spring 2009. Three additional treatments (C, D, and E) will be planted for the first time in Spring 2009.

I.D.	Treatment
A	Control: Initial cut and mulch (Fall '07) only
B	Initial cut + Spring '08 soil scarification/seedling removal before planting
C	Initial cut + Spring '09 herbicide before planting
D	Initial cut + Spring '09 scarification/broom removal before planting
E	Initial cut + stimulation of seedbank in fall '08 + scarification/broom removal in Spring '09 before planting
F	Initial cut + seedling removal in Spring '09 + Spring '10 before planting

Treatments for the POST experiment received no additional broom control before planting Douglas fir seedlings, rather this experiment focuses on mechanical vs. chemical control and number of years of follow-up treatment after planting (Table 2). In Year 1, two treatments will compare the efficacy of mechanical vs. herbicide control, and will allow comparison of the density of broom growth of both these treatments to the unmanipulated control. The assignment of the last three treatments in the POST experiment will be deferred until after we have the results of the first year's comparisons, following an "Adaptive Management" approach. Depending on the response to the herbicide vs. mechanical control, we may add different herbicide treatments, and depending on the rate of growth of broom plants, we may treat every year, every other year, or every third year.

Table 2. Treatments: POST-Planting Experiment. For the post-planting experiment, we have the following treatments. All treatments start with adult broom control in fall/winter 2007 and were planted March 2008 (=Year 0). Because of mortality, all post-planting blocks will be partially replanted November 2008.

I.D.	Treatment
A	Control: Initial control and planting (Year 0)
B	Mechanical broom control (cutting), Year 1.
C	Chemical broom control (herbicide, backpack sprayer), Year 1.
D	To be decided based on Year 1 results.
E	To be decided based on Year 1 results.
F	To be decided based on Year 1 results.

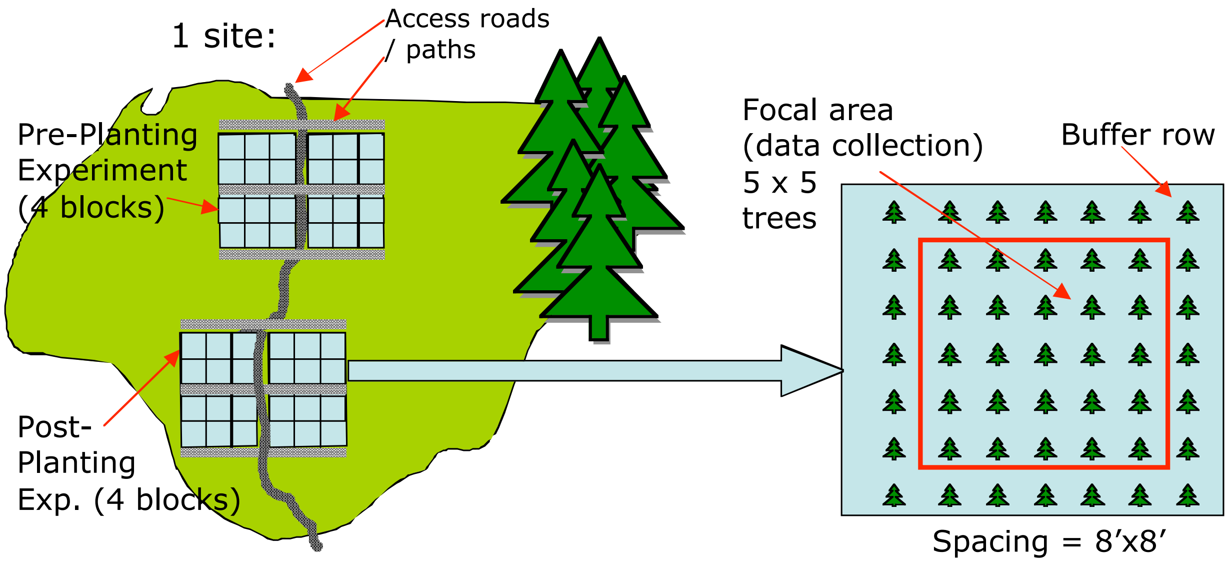


Figure 1. Generalized experimental design for PRE and POST experiments. Each site contains four blocks per experiment, with six plots per block and 49 trees planted per plot.

The experiments ("PRE" and "POST") make use of the same basic structure (Figure 1), based on 56' by 56' square plots, with 49 (7 x 7) trees at 8 foot spacing. Plots are structured into blocks of six plots, with four blocks per site. The total area for each experiment is 1.72 acres per site, or 3.44 acres per site for the two experiments.

Site Descriptions

Five sites were chosen by Fort Lewis for Scotch broom removal and experimental treatment: Nisqually Bridge, Johnson Marsh, Beal Hill, Tanktable, and Rumble Hill (Figure 2). Tanktable and Rumble were chosen to replace Rocky Ridge and Warner Woods sites, two sites that had originally been selected in fall 2007 but were dropped for safety reasons. All sites except for Beal are large enough to accommodate both experiments. At Beal, only the post-planting experiment was done.

Figure 2. Relative locations of the five experimental sites.

Johnson Marsh (Appendix 1A)

Johnson Marsh is the easternmost site of the project, located at 47°02.831'N, 122°29.645'W in Training Area 10a. The terrain is hummocky, sloping gently N/NE at the northernmost edge of the site.

Nine months after broom removal, grasses are the dominant vegetation, and Johnson has the lowest density of shrubs and forbs of any site. *Mahonia aquifolium* (Oregon grape, Berberidaceae) is the dominant shrub at Johnson. Other common shrubs and herbs include *Symphoricarpos sp.* (snowberry, Caprifoliaceae), *Hypericum perforatum* (St. John's wort, Hypericaceae), and *Tanacetum vulgare*. Johnson is the most open of the sites, with few trees within the plots. The grassland expands well beyond the experimental plots, and the site surrounding the plantation is an apparent mixture of prairie and Douglas fir forest. Scotch broom thickets span the forest edge at the westernmost side of the site. Stands of young Doug fir are present at the northern and southern areas of the site.

Tanktable (Appendix 1B)

Tanktable is located at 47°2.4400'N, 122°36.9517'W in Training Area 5. The terrain at Tanktable is flat.

Dominant shrubs and herbs at Tanktable include *Rubus ursinus* (Wild blackberry, Rosaceae), *Pteridium aquilinum* (Bracken fern, Polypodiaceae) and snowberry. Nine months after broom removal, grasses are overall the dominant vegetation type, and the grassland extends well beyond the experimental plots. Several even-aged stands of young Doug fir (<15') occur within the site, particularly at the NE and S/SE edges of the site. Surrounding the prairie from the N, E, and S is mature Doug fir forest. The western edge of the site is bordered by grassland with scattered mature Doug fir, extensively invaded by Scotch broom thickets. This broom was cut in the summer of 2008.

Rumble Hill (Appendix 1C)

Rumble Hill is located at 47°2.8183'N, 122°39.9600'W in Training Area 4. The POST blocks run adjacent to the entry road, with block 1 at the bottom of a hill, and blocks 3 and 4 at the top of the hill. PRE blocks at Rumble are also variable in their topography. PRE blocks 3 and 4 slope E, and block 2 slopes gently to the N/NW. PRE block 1 is downhill from blocks 3 and 4.

Dominant vegetation type varies with topography at Rumble. Lower elevations, in particular POST 1, PRE 1 and 2, are dominated 9 months after broom removal by dense grass, Bracken fern, and *Solidago sp.* (goldenrod, Asteraceae). Shrubs dominate the steeper rises, in particular POST blocks 3 and 4. Dominant shrubs include snowberry, Oregon grape, and St. John's wort. Forest surrounds the site from the E and S sides, dominated by Doug fir with some hardwood species mixed in. A dense and expansive thicket of Scotch broom extends along the northern edge of the site.

Beal (Appendix 1D)

Beal is the northernmost site of the project and is close to the residential area of Fort Lewis, located at 47°4.4983'N, 122°37.1050'W in CTA B. The terrain is flat.

Beal is the smallest site and is most densely surrounded by Douglas fir forest. Nine months after broom removal, grasses are the dominant vegetation in the plots, although there are a number of different species of shrubs and forbs. Wild blackberry is the dominant shrub at Beal. Other common species include Oregon grape, St. John's wort, snowberry, and *Alnus sp.* (alder, Betulaceae). There are a number of mature Doug fir trees dispersed throughout the site, concentrated in the S/SW end, in POST block 1. Sun exposure is lower in this area than in other areas of the plot, and is lower across the site than other areas because of the surrounding forest, dense on all sides except for the NW edge.

Nisqually Bridge (Appendix 1E)

Nisqually Bridge is the westernmost site of the project, located at 46°59.475'N, 122°38.632'W in Training Area 19. The terrain is generally flat, with several depressions within the POST blocks 1 and 2.

Nisqually has a lower grass density and a greater shrub and forb density than any other site. At 9 months after broom removal, snowberry is the most dominant shrub at Nisqually. Also present are *Brassica campestris* (Common mustard, Brassicaceae), Wild blackberry, St. John's wort, and Oregon grape. There are several mature and many small (<10') Doug fir trees located within the POST blocks. In addition, small (<10') broadleaf trees are scattered throughout the site. Species of broadleaf trees found within the site include alder and *Quercus garryana* (Oregon white oak, Fagaceae). Doug fir and mixed hardwood forest surrounds the site from all sides. At the northernmost edge of the site, dense Scotch broom thickets line the edges of the forest.

Methods

Site reconnaissance

In October 2007, Parker and Haubensak came to Fort Lewis to investigate the proposed experimental sites (Nisqually Bridge, Johnson Marsh, Beal, Rocky Ridge, and Warner Woods) before Scotch broom control was begun. We walked through the thick broom growth at each site. From November through February the broom was cut at all sites using large, mechanical brushcutters, although different contractors treated the different sites, and their techniques varied among sites. Therefore the amount of soil scarification, and the number and height of broom stumps remaining also varied among sites.

Experimental setup

During March 23-30, 2008 (in approximately 360 person hours), an 8-person field crew from UC Santa Cruz mapped out and established the general outline of all blocks, set up all 216 plots, using PVC to mark the corners of each plot within the blocks. PVC posts in the PRE experiment were painted orange, those in the POST experiment were painted green. Once all blocks were surveyed, two plots per block in the PRE experiment were randomly assigned to the control treatment or broom seedling/stump removal treatment (Table 3). These two plots per block, plus all plots in all blocks of the POST experiment, were then prepared for tree planting.

In order to establish the seedling/stump removal treatment in March 2008, we chose between using a brushcutter or a bulldozer. We established two pilot test plots to compare the effectiveness of the brushcutter and the bulldozer for killing small seedlings. The plots were side by side at the south end of Tanktable, with the brushcutter plot to the west of (closer to the road than) the bulldozer plot. We inspected the brushcutter plot after one pass and discovered substantial numbers of seedlings and grass surviving. It was suggested to the operator that a second pass be done at 90 degrees from the first pass. After the second pass, no live seedlings were found. In the bulldozer plot, no live seedlings were found, but it was not clear that the bulldozer could be used with precision at the scale of individual experimental plots. Therefore, the brushcutter was chosen for the experimental scarification treatment. However, we suggest that, with the right equipment operator, either a brushcutter or a bulldozer could be an appropriate tool to use for removing recently germinated broom seedlings at a large scale. In May 2008 we inspected the plots again briefly and found that it was very difficult to see any obvious difference between them. The berms produced from topsoil pushed by the bulldozer appeared to have a relatively large number of seedlings on them. However, because the layout of these plots was informal and the boundary was not marked, we did not collect quantitative data from them.

In every experimental plot to be planted, rows of dots were spray-painted at 8 foot spacing, to guide tree planters to place the seedlings at the correct points. After Darrell treated the 16 brushcutter plots, dots were also painted in these plots. A total of 49 dots per plot, or 7,448 dots, were painted.

Table 3. Assignments of PRE Experiment treatments to plot positions in the four blocks.

BLOCK 1

(A) Control	(F) Scarify Yr2,3
(E) Scarify 1Fall, 2	(D) Scarify Yr2
(C) Herbicide Yr2	(B) Scarify Yr1

BLOCK 3

(B) Scarify Yr1	(A) Control
(E) Scarify 1Fall, 2	(C) Herbicide Yr2
(F) Scarify Yr2,3	(D) Scarify Yr2

BLOCK 2

(B) Scarify Yr1	(C) Herbicide Yr2
(A) Control	(D) Scarify Yr2
(F) Scarify Yr2,3	(E) Scarify 1Fall, 2

BLOCK 4

(D) Scarify Yr2	(A) Control
(E) Scarify 1Fall, 2	(F) Scarify Yr2,3
(B) Scarify Yr1	(C) Herbicide Yr2

Trees were planted March 31-April 4 by Ramos Reforestation. Two-year old trees (Plug-1) were provided by Silvaseed Company, Roy, WA. The seed lot used was 212-05. We expect to use this same seed lot for planting into the experiment in 2009 as well.

Broom stump density

In all plots in all sites, we estimated the initial density of broom stems. These data are intended to provide relative information about the initial (pre-brushcutter) broom densities in the different sites and blocks.

The data have two weaknesses: 1) because the size of broom plants can vary greatly, the number of stumps does not provide a perfect estimate of the "broom influence" at the site (some plots had many small stumps while others had few large ones), and 2) sites that experienced more thorough site prep may have had some stumps removed entirely. However, we felt these data were the best that could be collected, and we believe they do provide useful information, especially as a relative measure within sites.

Initial densities of broom stumps were estimated from 24.1m-long, 0.5m-wide belt transects across the hypotenuse of each plot from the lower right corner to the upper left corner. The belt transect was on the upper side of this line. For brushcutter plots, stump density was recorded in March 2008, in order to capture these data before destroying the stumps in these plots; for the remainder of the plots, stump density was recorded in September 2008.

Broom germination

In March 2008, we collected baseline data on Scotch broom germination. These data provide information about the relative size of the initial seed bank in the different sites. As with stump density, however, certain caveats must be kept in mind, particularly that the timing of site prep varied across sites and therefore there might have been more time for seeds to germinate in some sites than others. In order to test for this, we assessed germination a second time later in the season in a subset of plots.

Seedlings were counted in a 24.1 m-long, 10cm-wide belt transect on the lower side of the line from the lower right corner to the upper left corner of every plot. The number of broom seedlings was recorded for every 3m segment of this belt transect, providing 8 (spatially contiguous) samples and a total of 2.4 square meters of sampled area per plot.

In May 29-June 2, 2008, we counted seedlings again in the same belt transects, for a subset of one plot per block. These data gave us information on relative phenology across sites, and relative numbers of germinants early vs. late in the spring.

Frequency of stump resprouting
In order to understand factors influencing the rate of stump sprouting within sites, from May 29-June 2 we marked 5 stumps in each plot with a vinyl flag (1,080 flagged stumps total). The flags allow us to re-find stumps, even in thick grass and after decomposition occurs. We revisited all flagged stumps in September 2008, and we measured their diameter (= size at time of control) and their height (= height above the ground at which they were originally cut).

Douglas fir survival and initial size
In May 29-June 2, and again September 4-12, 2008, we measured the height and reviewed the status (dead, partially dead, or alive) of each of the 25 focal tree seedlings in all plots in all sites, a total of 3,800 trees. Stephanie Kimitsuka collected these data with Ian MacKay in spring and with Stephen Hartwell in fall.

In addition, we measured the height of all focal tree seedlings in May 29-June 2, providing data on initial size at planting.

Analyses and Results

Here we provide statistical analysis and interpretation of results in four areas describing initial conditions: Initial broom stump density, Initial broom stump diameter and cutting height, Initial broom seed germination, Phenology of broom seed germination. We then present data on two aspects of the ongoing dynamics: Frequency of stump resprouting, and Douglas fir survival.

Initial stump density
How does the initial density of mature broom, estimated from remaining stumps, vary from site to site and within sites?

Cytisus stump density in May-June 2008 was much higher at Rumble than at the other sites (Figure 3). Variation in (log-transformed) stump density was highly significant among sites for both the PRE experiment (DF=3,76, F=57.7, P<0.0001) and the POST experiment (DF=4,100, F=49.4, P<0.0001).

Variation among blocks within site was not significant for the PRE experiment, which did not include Beal (DF=12,76, F=1.3, P = 0.25). There was moderate and significant variation among blocks within sites for the POST experiment (DF=15,100, F=2.1, P = 0.016).

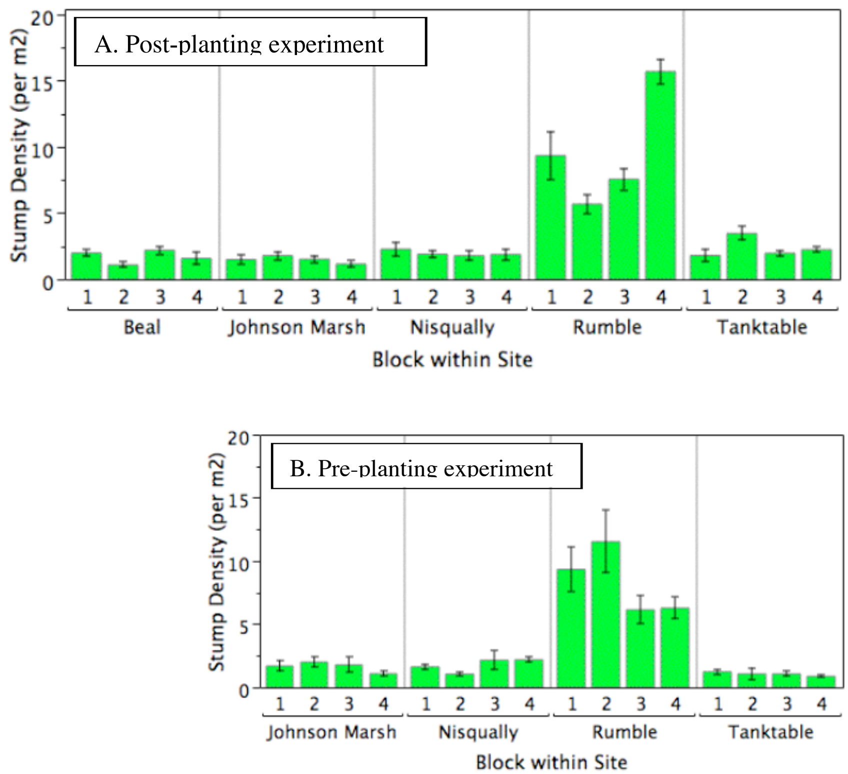


Figure 3. Initial densities (means ± 1 SE) of broom stumps after removal of adult broom and before planting of Douglas fir seedlings. March 24-29, 2008.

Variance among sites contributed over two-thirds of the total variance in stump density (Table 4). Most of the rest of the variance was distributed among plots (which were the unit of replication in this part of the study). As with seedlings (see below), the variance among blocks (within sites) was only a minor component of the total variation in stump density.

Table 4. Estimated components of variance in *Cytisus* stump density (using REML, JMP 6.0, SAS Institute.). Data collected May 29-June 2, 2008.

	Pre Experiment	Post Experiment
Site	66.4%	69.5%
Block	1.1%	2.5%
Plot (Residual)	32.5%	27.9%

Conclusion:
There was a great deal of variation in stump density among sites, with Rumble having by far the most stumps. Over two-thirds of the variance in stump density was associated with differences among sites, with almost no variance among blocks within sites.

Initial stump diameter and height
How does average size of broom plants at time of control vary across sites? How does the mean height of stumps, possibly reflecting the care of the operator, vary across sites?

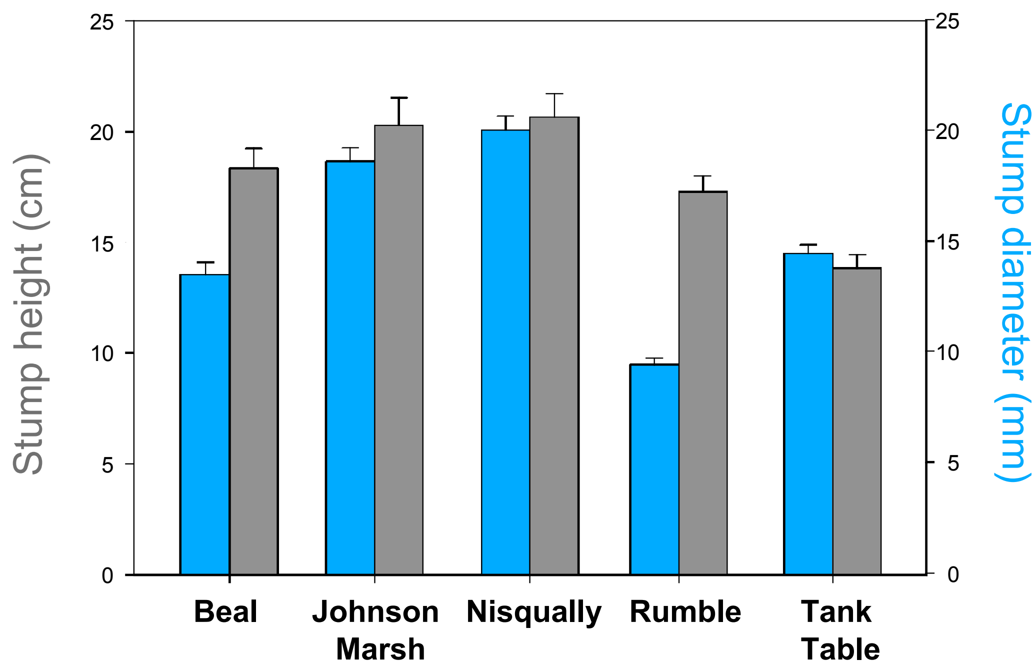


Figure 4. Mean (+ 1 SE) stump height in cm (gray bars, left axis) and stump diameter in mm (blue bars, right axis) across the five sites.

We found significant variation among sites for stump diameter ($F_{4,979}$=9.12, $P < 0.001$). Broom plants at Rumble were the smallest/youngest, averaging around 1 cm in diameter, while plants at Johnson Marsh and Nisqually were close to twice that size (Figure 4).

Stump height, which reflects how close to the ground the plants were cut, also varied significantly across sites ($F_{4,979}$=76.7, $P < 0.001$). Plants were cut closest to the ground (<15 cm) at Tanktable; in contrast, Beal, Johnson Marsh, and Nisqually were all closer to 20 cm on average (Figure 4). It is interesting to note that none of the sites had a mean stump height of below or close to the 4 inch (=10 cm) goal originally specified by Fort Lewis.

Initial seedling number
How does germination of broom seedlings from the seed bank vary from site to site and within sites?

Scotch broom seedling density in March 2008 showed extreme variation among sites (Figure 5). Johnson Marsh and Rumble had very low seedling densities, Beal was intermediate, and Tanktable and Nisqually had high seedling densities, sometimes exceeding 100/m^2 on average. There was a highly significant variation among sites for both the Pre-Planting experiment (DF=3,80, F=112.8, P<0.0001) and the Post-Planting experiment (DF=4,100, F=87.5, P<0.0001).

There was significant variation among blocks within sites for the Post-Planting experiment (DF=15,100, F=1.89, P = 0.032) but not for the Pre-Planting experiment (DF=12,80, F=1.2, P = 0.30). Note that Beal was only included in the Post-Planting experiment, and the variability among blocks at Beal (Figure 5) probably drives this difference between the two experiments.

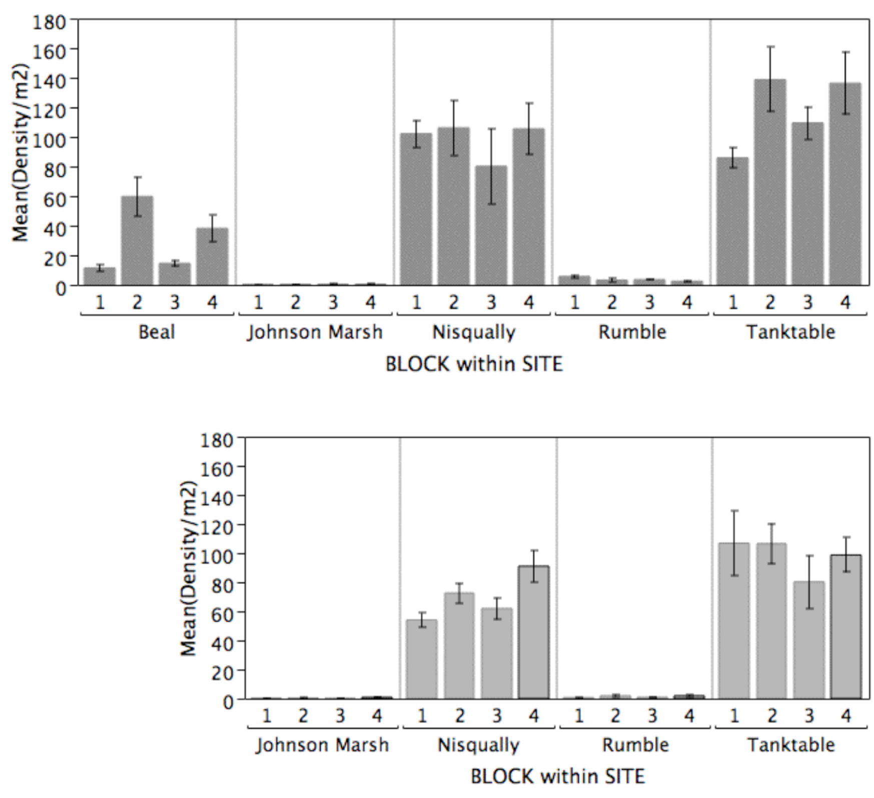


Figure 5. Initial densities (means ± 1 SE) of broom seedlings after removal of adult broom. March 24-29, 2008. Upper panel: POST Experiment; lower panel: PRE Experiment.

Variance among sites contributed over half of the total variance in seedling number (Table 5). Another third of the variance was distributed among samples (2m x 10cm segments) within plots. Only about 10% of the variance was due to variation among plots within blocks, and there was almost no variation among blocks within sites, suggesting that broom seedling densities are fairly homogeneous at the intermediate scale. Thus broom seedlings are patchy at a very local scale (meter to meter), that patchiness is then relatively homogeneous within sites, while sites differ greatly from each other.

Table 5. Components of variance in seedling density (from REML, JMP 6.0, SAS Institute.). Data collected March 24-29, 2008, after removal of adult broom and before planting of Douglas fir seedlings.

	PRE Experiment	POST Experiment
Site	57.5%	55.8%
Block	0.4%	2.3%
Plot	8.1%	11.9%
Quadrat (residual)	33.9%	29.9%

Phenology of germination

Are seedling numbers in March highly predictive of seedling numbers in May, or does variability in phenology have a strong influence over variability in numbers of broom seedlings in each plot? Do patterns among sites hold up from March to May?

There was a strong linear relationship between seedlings in March and seedlings in May (square-root transformed data, Sqrt(May) = .43 + 1.44 Sqrt(Mar), N=36, P<0.0001, R^2=0.90). Even in the non-transformed data, 84% of the variance in seedling numbers in May was explained by numbers in March (Figure 5, May = -12.6 + 2.38 * Mar, N=36, P<0.0001, R^2=0.84).

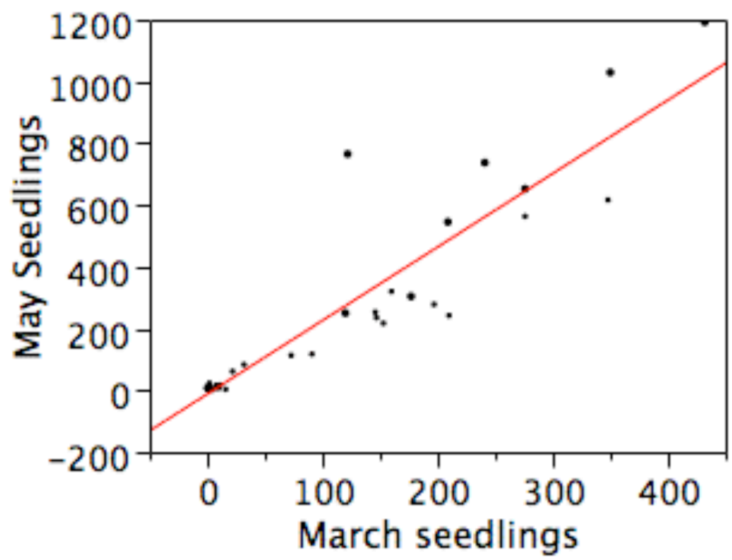


Figure 6. Total number of seedlings (in 2.4 m^2 of belt transect from each plot) in May as a function of seedlings in the same plot in March.

There were about twice as many seedlings counted in May as in March (Figure 6). This suggests about half of all seedlings germinated before March 29 and the other half germinated in April or May. This means that in order to do effective mechanical control of *Cytisus* seedlings, one would have to wait until it would be too late in the spring to plant trees, which need to be in the ground by March. Such temporal tradeoffs place problematical constraints on management options.

Because of the close correspondence between March and May germination numbers, May data showed the same patterns as seen in the March data (Figure 7).

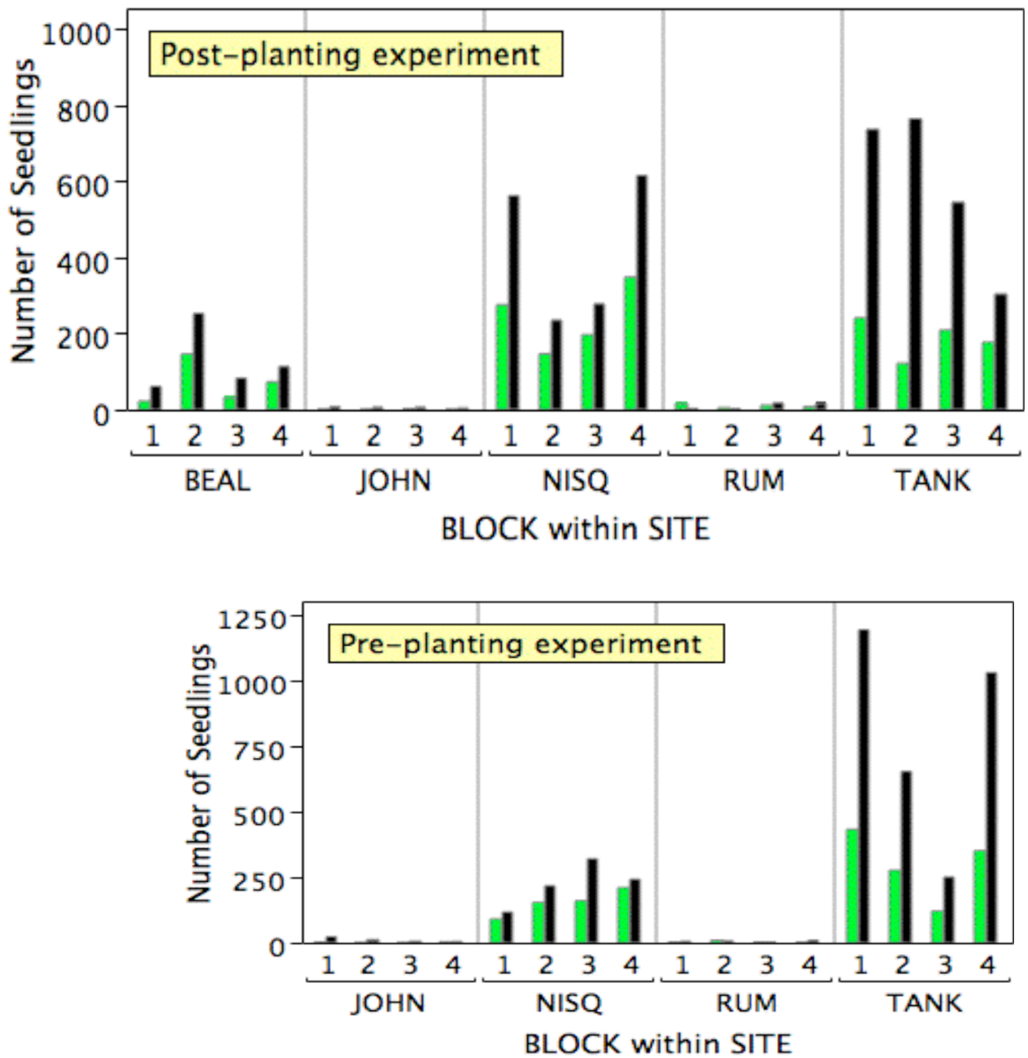


Figure 7. Patterns of variation in seedling numbers among sites and among blocks within sites, in March (green) and May (black).

Stump resprouting:
Does the resprout rate of stumps vary from site to site?
Does initial plant size at time of cutting influence the probability of resprouting?
Does the height at which cutting is done (height of stump) influence the probability of resprouting?

The resprout rate of stumps was low in four of the five sites, averaging between 4% and 13% of stumps (Figure 8). In contrast, one site (Rumble), showed a shockingly high resprout rate of 36%, several times higher than that in the other sites. Variation in resprouting within sites was small compared to the variation among sites (Figure 8).

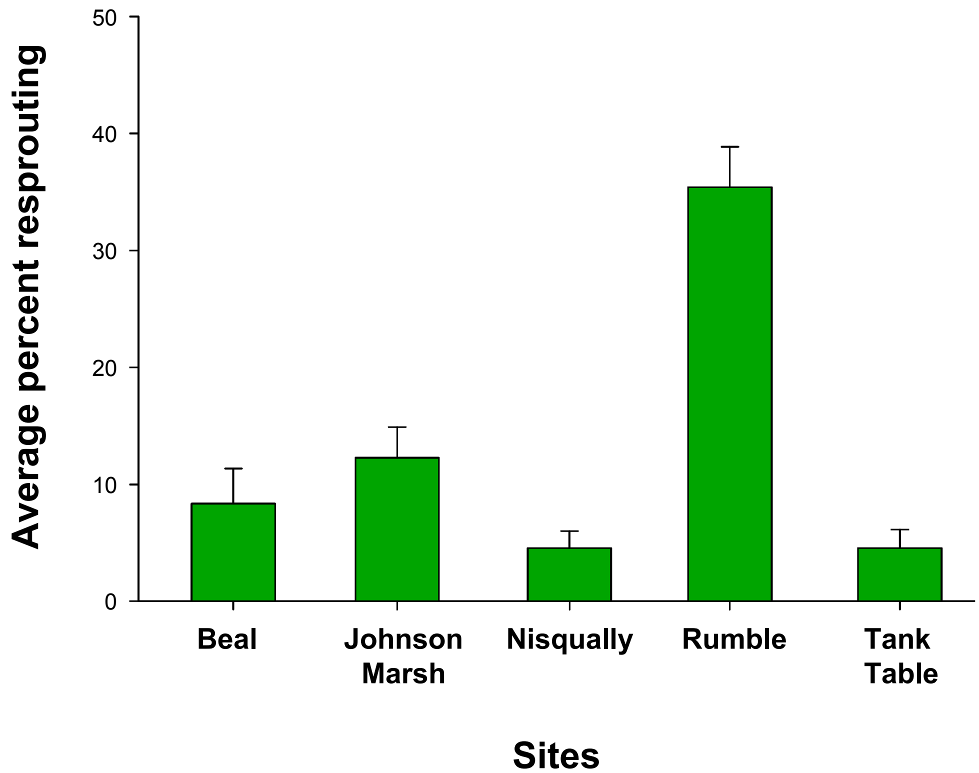


Figure 8. Percent of stumps (means ± 1 SE) resprouting at each of the five sites. Plots within blocks were treated as replicates, 5 stumps were marked per plot.

We were able to use data from the 1080 individually-marked stumps to test for the effects of plant size (stump diameter) and brushcutter quality (stump height) on the probability that stumps would resprout. Because diameter and height vary among sites, and resprouting also might vary among sites for reasons unrelated to diameter and height, this analysis must be blocked for site. This means that information can be combined across the five sites but that stumps must not be pooled as if they were from the same site. We performed a nominal logistic regression using site as a (random) blocking factor and predicting the probability of resprouting from diameter and height of the stump.

While site was a highly significant factor (χ^2 = 95.8, DF=8, P<0.0001), neither stump diameter (χ^2 = 1.74, DF=2, P=0.42) nor stump height (χ^2 = 1.43, DF=2, P=0.49) significantly predicted within sites whether a broom plant resprouted (Figure 9). This statistical result is consistent with anecdotal observations we made in the field in both May-June and September 2008, that resprout rates varied greatly from site to site and that we could not discern obvious factors that explain why certain areas or individual stumps had higher rates of resprouting.

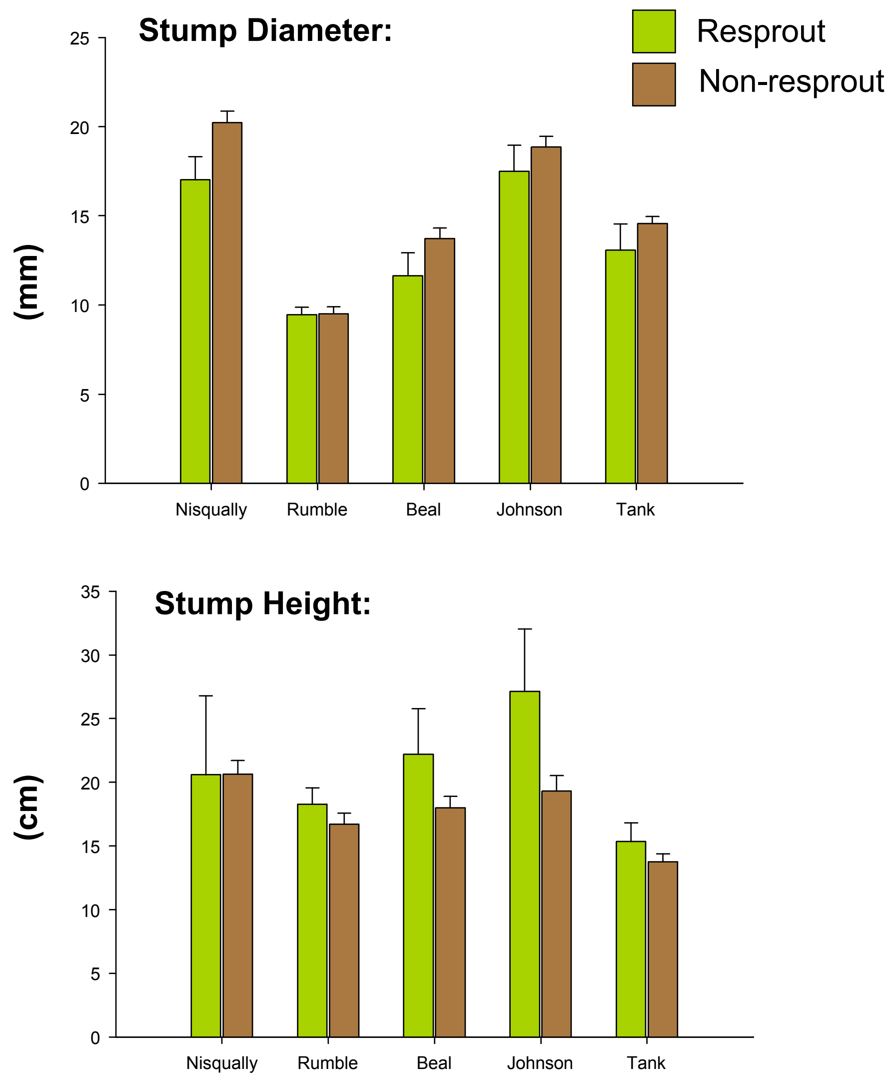


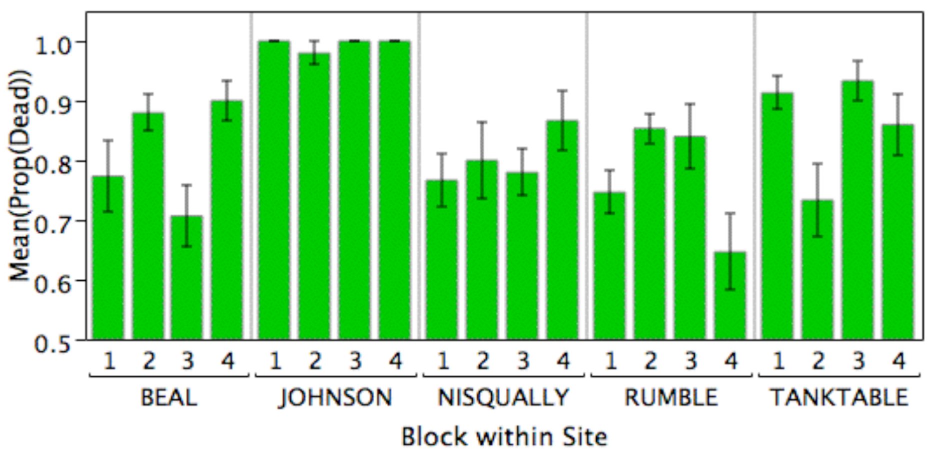
Figure 9. Comparison between resprouting and non-resprouting stumps for stump diameter (top) and stump height (bottom). Neither factor significantly predicts resprouting. Shown are means 1 SE.

Conclusion:
While it is frustrating that we have not unlocked the secret of why some stumps resprout and others don't, we have gained some important new knowledge. First, it does not appear that the height of the brushcutting (within the range of

heights we observed) is a critical factor determining the kill rate. Second, we now know that this factor varies enormously from site to site and will have a highly variable degree of influence over the success of broom control. In our future work, we may find that the extensive resprouting at Rumble will be a major driver in determining which management strategies are most effective at that site relative to others.

Douglas fir survival

Over half of all Douglas fir seedlings died between March and September in almost all blocks of both the PRE and POST Experiments (Figure 10). In the POST experiment, there were substantial and statistically significant differences in mortality among sites ($F_{4,100}$=17.2, P <0.0001) and among blocks nested within sites ($F_{15,100}$=3.10, P=0.0004). In the PRE experiment, there was significant variation among sites ($F_{3,16}$=5.4, P =0.0094), but not among blocks nested within sites ($F_{12,16}$= 0.63, P =0.79). Johnson Marsh experienced almost complete mortality across the board (Figure 10).



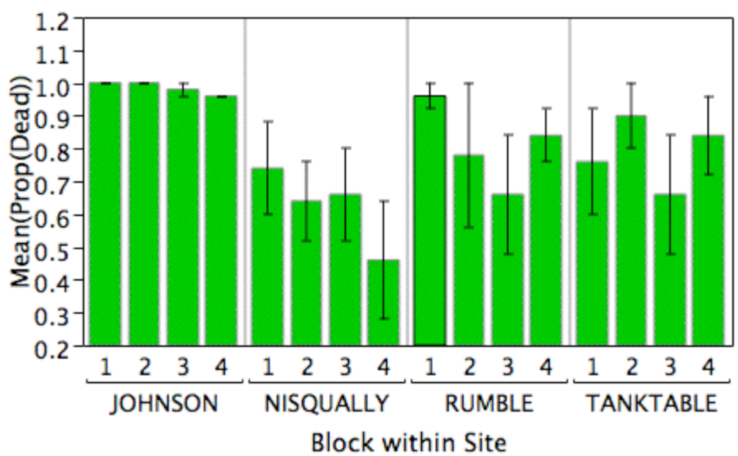


Figure 10. Proportion of dead (and near-dead) Douglas fir seedlings (means ± 1 SE). Sept. 1-12, 2008. Upper panel = POST Experiment; lower panel = PRE Experiment.

From the original planting treatments, we were able to make a comparison between control plots (Treatment A, Table 3) and plots that were scarified with the brushcutter before planting in March ("Darrell plots," Treatment B, Table 3). Blocking the analysis by plot nested within site, we found that mortality was significantly lower in the plots that received extra scarification than in the controls ($F_{1,15}$=8.9, P =0.0092), a difference of about 20% (Figure 11). This result may indicate that trees in the scarified plots experienced reduced competition from all vegetation, particularly grasses, which grew back aggressively after broom removal. Because broom seedings did not attain a substantial size in the first summer, we do not believe that competition from broom is implicated in this result.

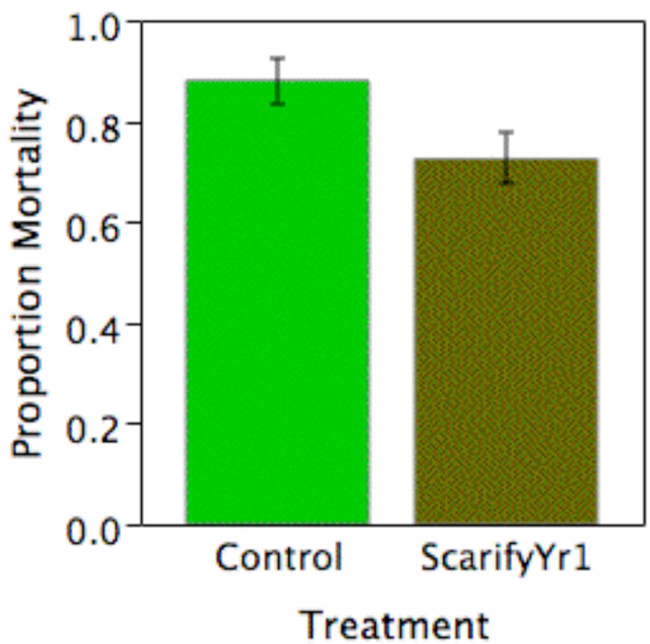


Figure 11. Proportion mortality of Douglas fir seedlings from March to September in Control plots vs. plots that went through another soil scarification treatment before planting in March (i.e., "Darrell" plots). Error bars represent ± 1 SE.

Edge effects on Douglas fir establishment

A separate pilot study was laid out to study the influence of proximity to the edge of remnant forest on tree establishment and competition from Scotch broom. At Johnson Marsh, two areas, 40 feet (12.2m) wide by approximately 200 feet (61m) long, were defined starting at a southern edge and a northern edge in March 2008. Approximately 400 trees total were planted into these areas, using the same seed source and planting crews as the experiment above. We did not set up a specific planting grid for these trees; rather, they were planted using a more typical, irregular 8 foot (2.4m) spacing.

In May-June 2008, we inspected the pilot experiment at Johnson Marsh. We briefly censused the trees in the two areas. Lack of time precluded collecting formal spatial data; however, we observed that there was a great deal of tree mortality and partial mortality at this site. It is too early to speculate in detail because we do not yet have data to analyze, but there may be an edge effect at least on one edge. In the north-facing area, trees closest to the edge appeared to be doing best, whereas in the other, south-facing area, we found a very high mortality rate that does not appear to be related to distance to the edge.

This experiment was designed as part of the senior thesis of undergraduate Ian MacKay. In the wake of a devastating spinal cord injury and the loss of the use of both his legs and arms, Ian will no longer be able to collect the data from this experiment. September 3-6, 2008, Stephanie Kimitsuka collected a substantial dataset, including GPS locations, survivorship, and size, from these trees.

The survival of each tree was ranked on a scale from 0-4, based on the ratio of brown to green needles and the presence or absence of new growth. The ranking system is as follows:

0=DEAD 100% BROWN
1=DYING 80-99% BROWN, NO NEW GROWTH AT TIPS
2= ALIVE 40-80% BROWN
3= GOOD HEALTH 10-40% BROWN, NEW GROWTH AT TIPS
4= EXCELLENT 100% GREEN, NEW GROWTH AT TIPS

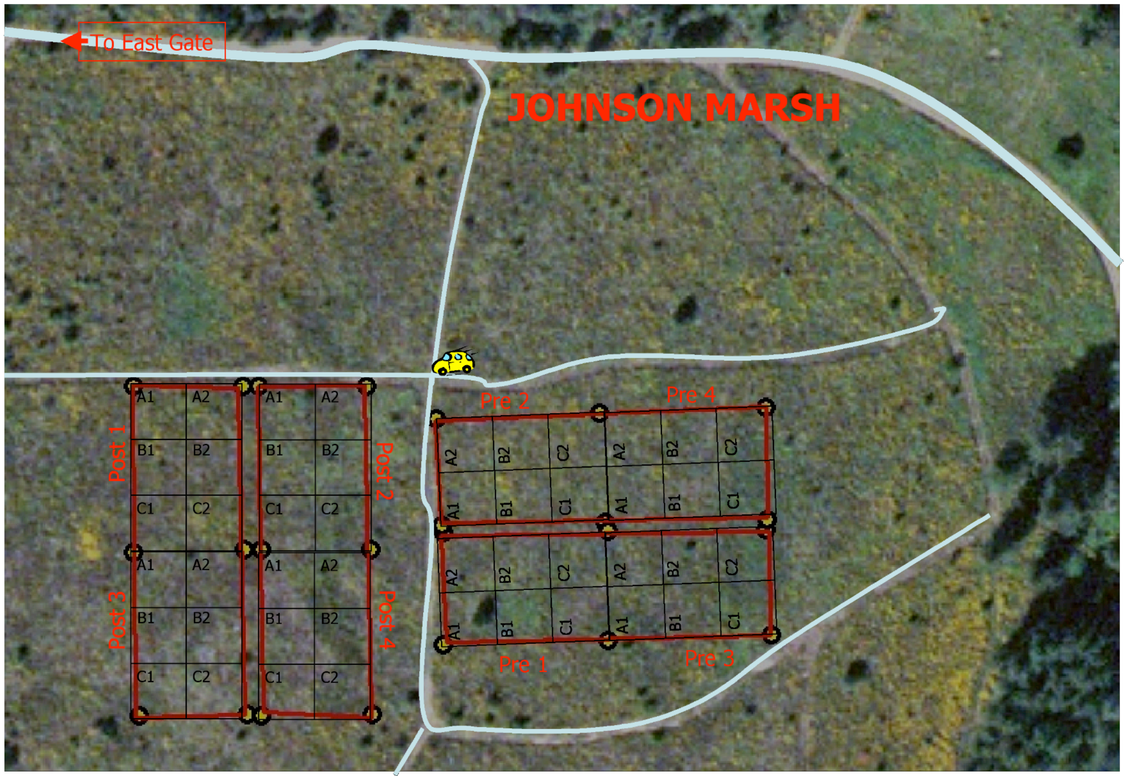
We observed 93% dead trees at the southern edge, and 95% dead trees at the northern edge. All trees that were not dead were given permanent tags numbered 963-999. The position of each tree (live or dead) was recorded using a Trimble GeoExplorer 2008 series GPS unit. In addition to survival and position data, we recorded the height and diameter at 15 cm for all trees. For trees that forked below 15cm, we recorded the height and diameter at 15 cm for each fork.

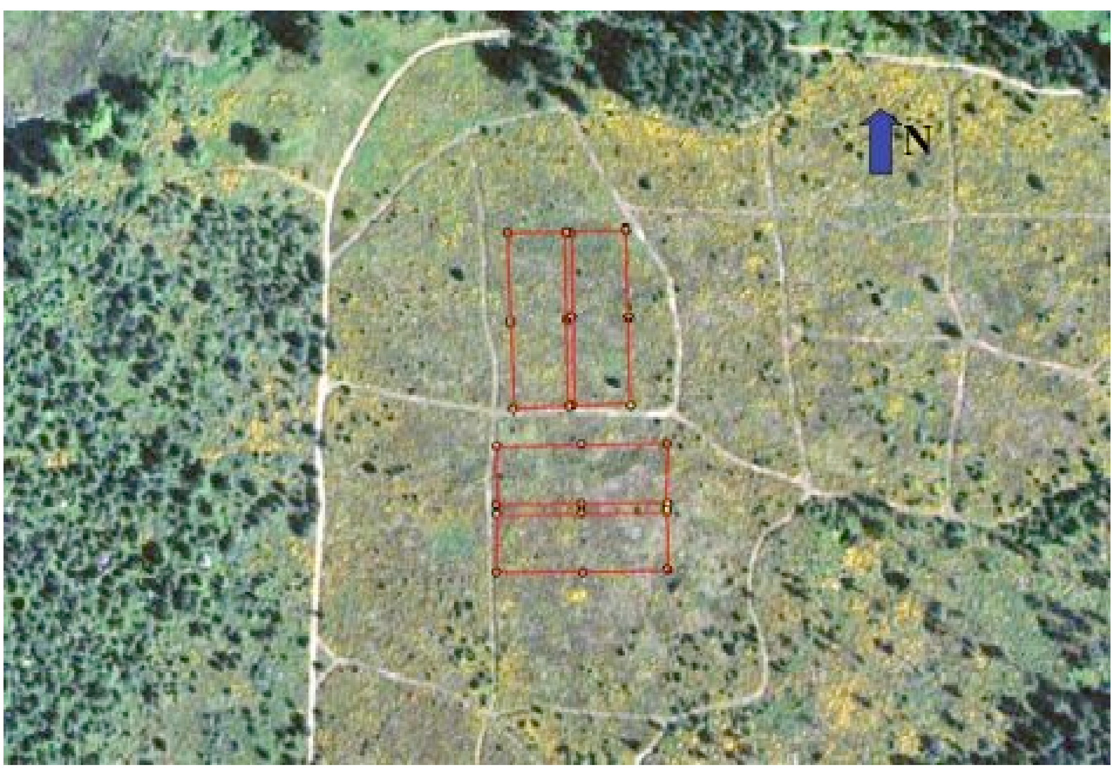
We also collected data on mature Doug fir trees that comprised the "edge" of each area. The circumference at 1.3 m from the base of each tree was recorded. We also estimated the height of each tree to the nearest 5 m. The positions of all adult trees within 25 m of the planted trees were recorded with the Trimble. Because there appeared to be an effect of shade on survival, the positions of other species of tree were also recorded. Other species of tree found within the two areas were *Pinus ponderosa* (Ponderosa pine, Pinaceae) and *Quercus garryana* (Oregon white oak, Fagaceae).

Although this study is a small-scale pilot study, we hope it will provide us with preliminary pattern information to help inform the larger question of the effect of forest edges on Doug fir and broom competition.

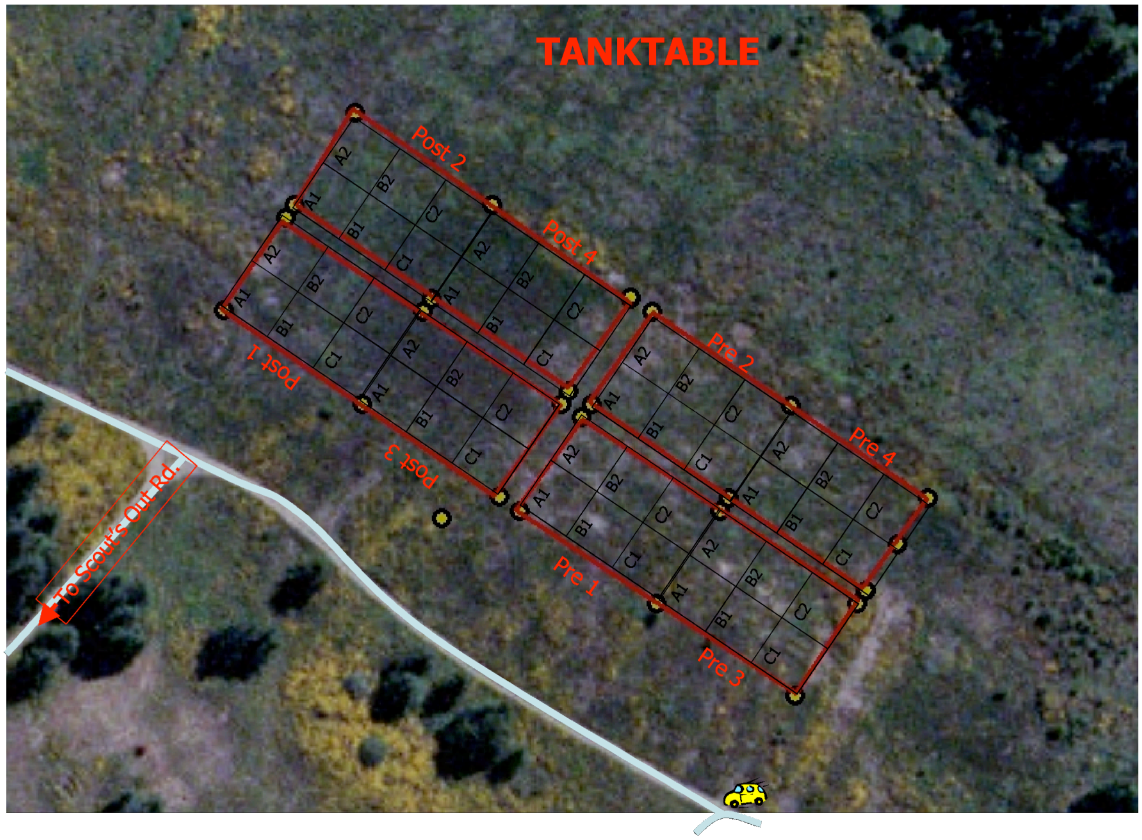
APPENDIX 1. Site maps with layout of experimental blocks.

Appendix 1a. Johnson Marsh Plantation.

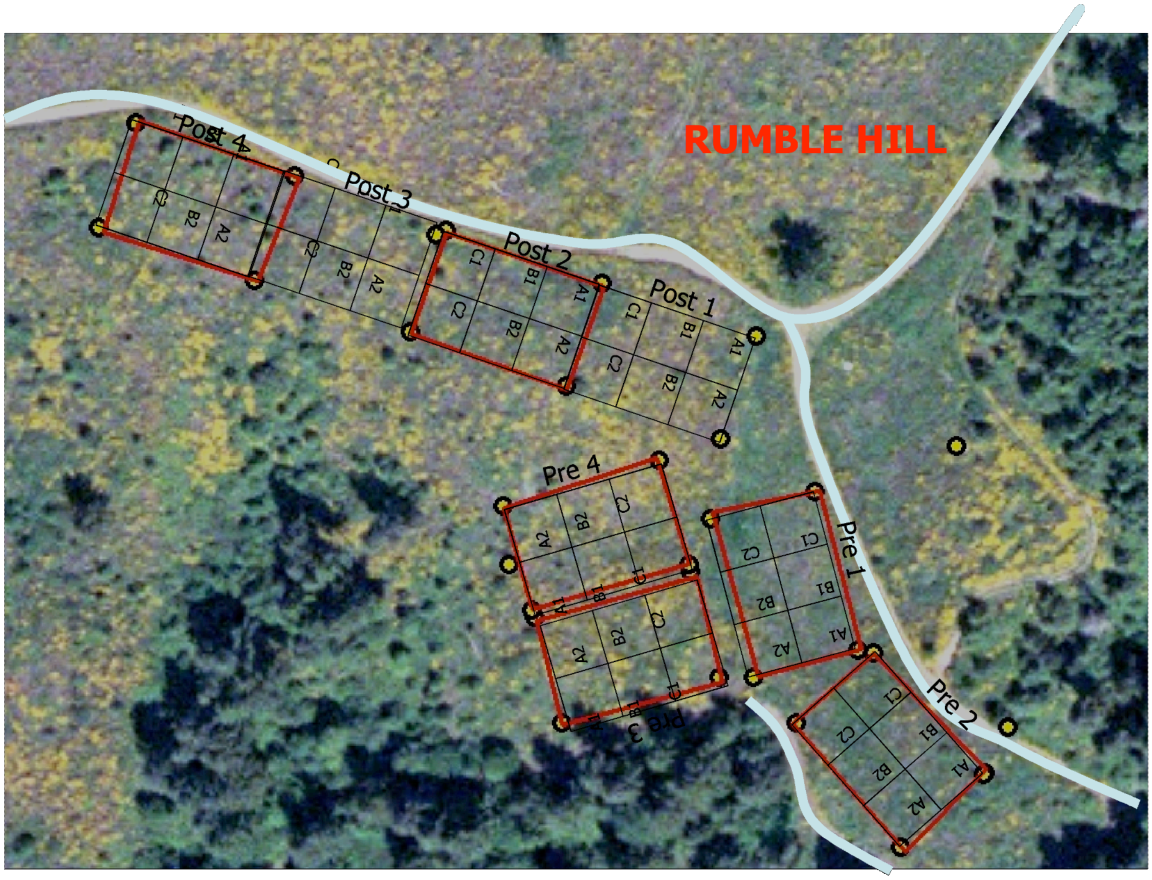


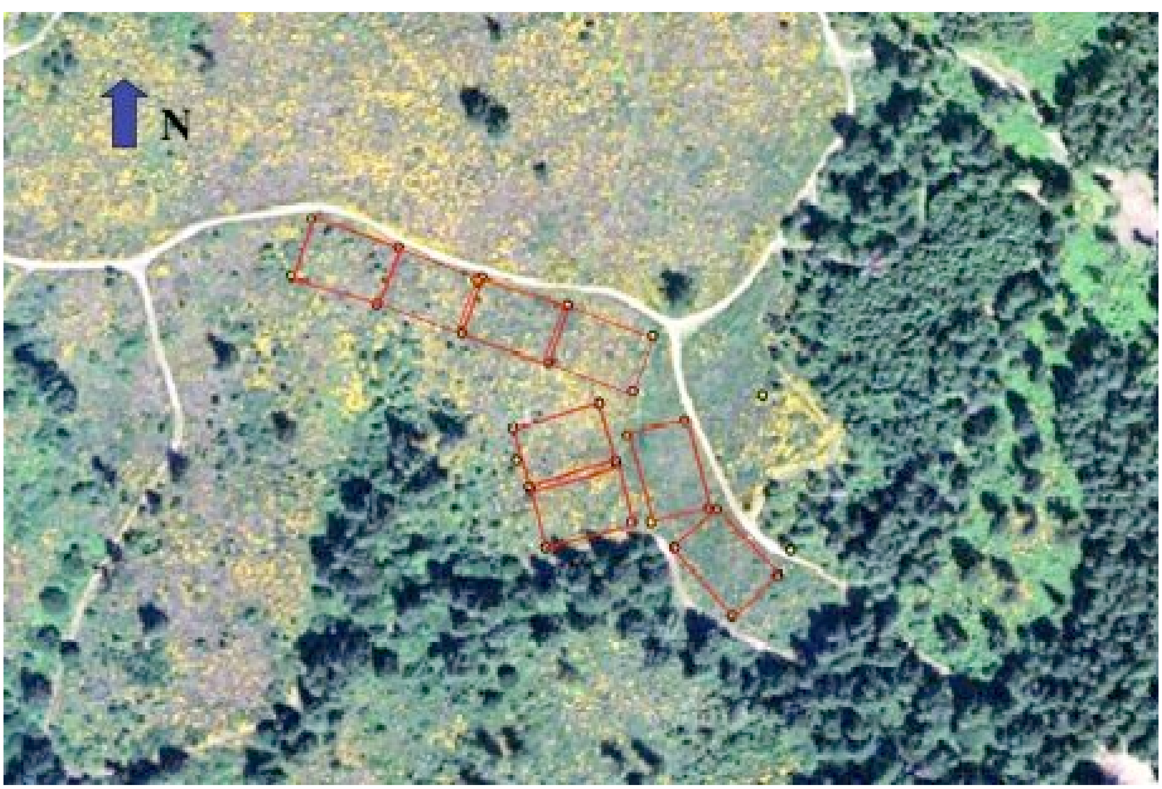


Appendix 1b. Tanktable

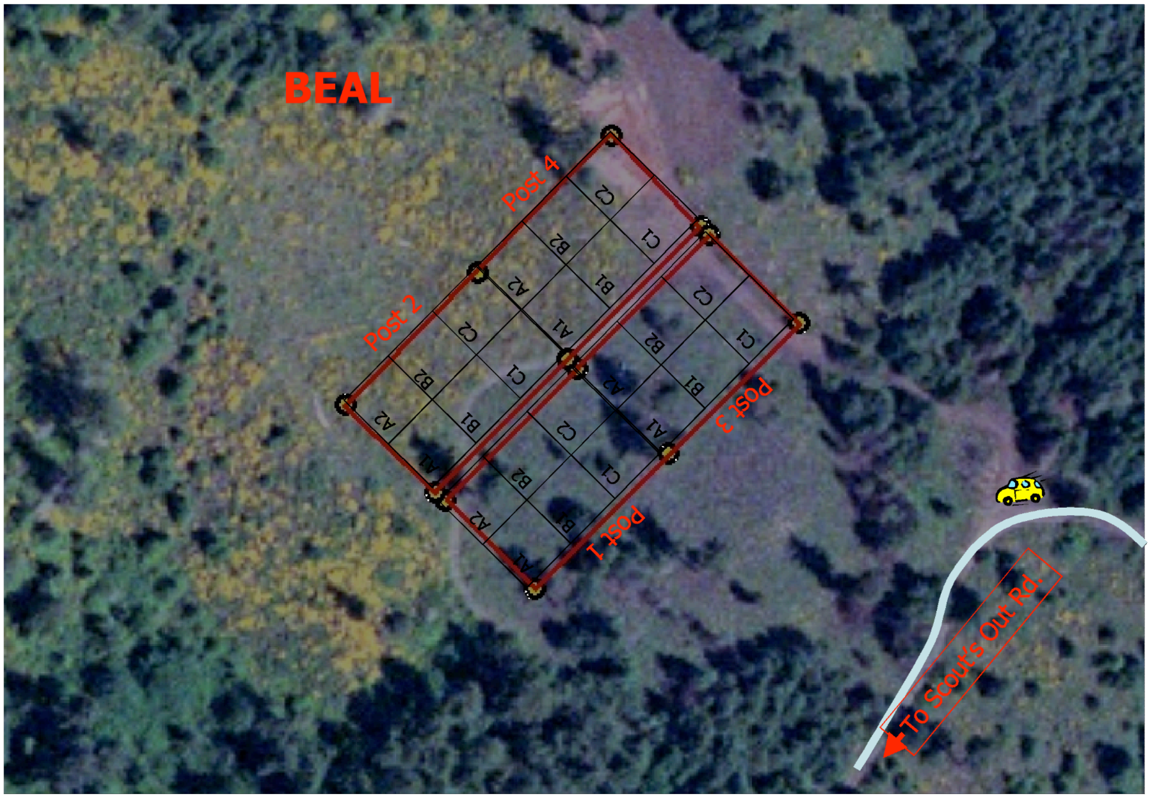


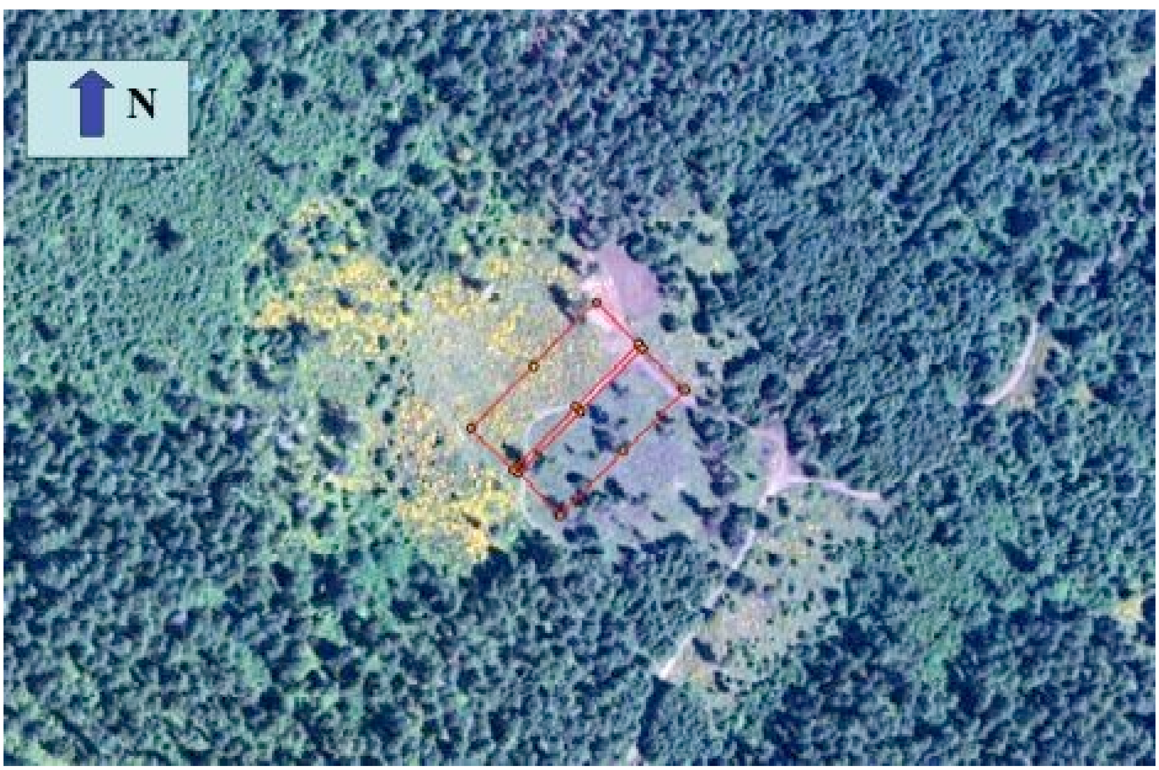
Appendix 1c. Rumble Hill.



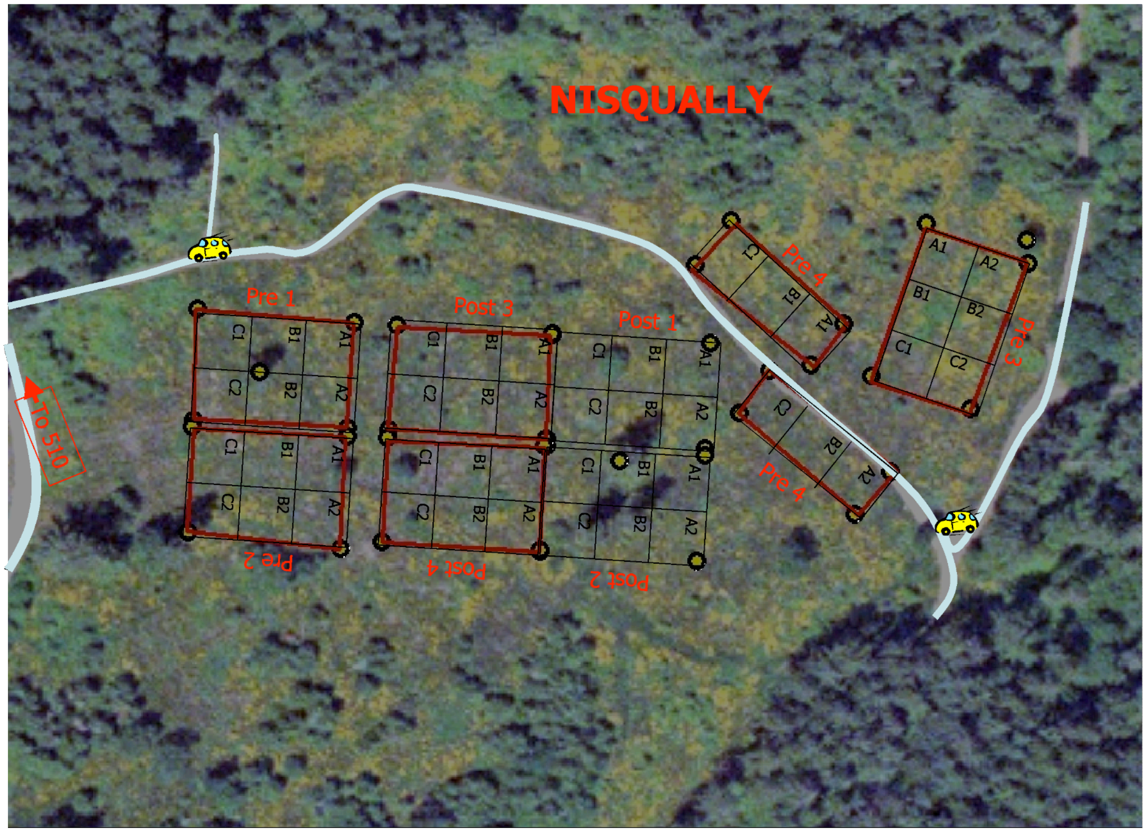


Appendix 1D. Beal.





Appendix 1E. Nisqually Bridge Plantation.



APPENDIX 2. Photo Documentation.

Figure 2-1. Johnson Marsh, October 2007, before broom control. Photo by I. Parker.

Figure 2-2. Beal, October 2007, before broom control. Photo by I. Parker.

Figure 2-3. Nisqually Bridge, July 2007, before broom control. Photo by I. Parker.

Figure 2-4. Johnson Marsh, March 2008, after site prep. Photo by I. Parker.


Figure 2-5. Tanktable, March 2008, after site prep. Photo by I. Parker.


Figure 2-6. Rumble Hill, March 2008, after site prep. Photo by I. Parker.

Figure 2-7. Beal, March 2008, after site prep. Photo by I. Parker.

Figure 2-8. Nisqually, March 2008, after site prep. Photo by I. Parker.

Figure 2-9. Ingrid Parker (left) and Karen Haubensak (right) collecting seedling density data. March 2008. Photo by S. Kimitsuka.

Figure 2-10. Planting Douglas fir seedlings, April 2008. Photo by N. Benson.

Figure 2-11. Douglas fir seedlings ready for planting, April 2008. Photo by N. Benson.

Figure 2-12. Live vs. dead Douglas fir seedling in May-June 2008. Photo by I. Parker.

Figure 2-13. Johnson Marsh, regrowth of vegetation, June 2008. Photo by I. Parker.

Firgure 2-14. Tanktable, regrowth of vegetation, June 2008. Photo by I. Parker.

Figure 2-15. Rumble Hill, regrowth of vegetation, June 2008. Photo by I. Parker.

Figure 2-16. Beal, regrowth of vegetation, June 2008. Photo by I. Parker.

Figure 2-17. Nisqually, regrowth of vegetation, June 2008. Photo by I. Parker.