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Assessing Light and Conifer Growth in a Riparian Restoration Treatment Along Spirit Creek, British Columbia

Abstract

Intensively harvested riparian stands in the Pacific Northwest sometimes require gap-creation or thinning of the deciduous canopy to promote conifer establishment and long-term restoration of the functions provided by large conifers. I assessed light availability and growth of planted conifers in a riparian restoration treatment along Spirit Creek, Vancouver Island, British Columbia. I used hemispherical canopy photographs and light-modeling software to assess light and predict growth of a shade-intolerant conifer, Douglas-fir, after gap creation. The canopy gaps (254-312 m^2) significantly increased the mean level of understory light from 16 to 30% of full sun while the range increased from 22 to 39%. Estimates from the literature (Drever and Lertzman 2001) of growth for regenerating Douglas-fir at post-treatment light levels range from 16-26 cm/yr. Measurements of height growth 2 yr after gap creation and planting corroborated these predicted values: > 90% of seedlings survived and showed mean height growth of ~ 16 cm/yr. Estimates of light availability from hemispherical canopy photographs combined with growth predictions from published light-growth relationships can therefore be used to improve the efficacy and reliability of restoration silviculture.

Introduction

Large conifers in streamside areas in the Pacific Northwest have many important ecological functions. They provide leaf matter for stream life and large woody debris (LWD) for the creation of large deep pools and other fish habitat, stabilize stream banks, moderate rainfall and peak flows, and shade the stream (Bilby 1981, Murphy and Koski 1989, Nakamura and Swanson 1992).

Clear-cut harvesting and other severe stand-replacing disturbances in the Pacific Northwest often create early successional stands dominated by pioneer hardwood species such as red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), and black cottonwood (*Populus balsamifera*) (Harrington 1990). The establishment of these stands in riparian areas can preclude conifer establishment, especially of shade-intolerant species (Newton and Cole 1994). These areas can lack the ecological functions provided by large conifers. For example, logs of deciduous trees such as red alder have shorter residency times in the stream than large conifer logs and cannot create and maintain the same type and quality of fish habitat (Lienkaemper and Swanson 1987, Bilby and Ward 1991, Hayes et al. 1996).

Creating canopy gaps in these hardwood dominated systems in combination with other treatments can promote the long-term restoration of riparian functions provided by large conifers by creating microclimatic and site conditions conducive to successful conifer establishment and growth (Chan et al. 1996, Slaney and Martin 1997). However, considerable uncertainty exists about what degree of thinning or opening creates light levels high enough to guarantee conifer survival and growth without compromising the riparian functions provided by the hardwood overstory (Hibbs et al. 1989, Chan et al. 1996). Other management uncertainties include the free-growing period, i.e., the time during which competing vegetation may reduce the growth and survival of planted trees (Klinka et al. 1990). Because many restoration silvicultural treatments involve retention of partial canopies and therefore shading of regeneration, the length of time required to establish a cohort of trees free of competition is not well understood.

Light availability is a good predictor of growth rates of many species regenerating in a variety of field conditions (Wright et al. 1998, Coates and Burton 1999). Drever and Lertzman (2001) determined the growth response to light for regenerating coastal Douglas-fir (*Pseudotsuga menziesii*) —a fast-growing, shade-intolerant and long-lived conifer of principal interest in this study – for different soil and moisture regimes. Variation in light explains 62-81% of variation in height growth for Douglas-fir depending on site type (Drever and Lertzman 2001).

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In this study, I assessed whether artificial canopy gaps create an understory light environment suitable for regeneration of Douglas-fir. I also provided an example of how hemispherical canopy photography can be used to quantify the degree to which silvicultural treatments modify the resulting understory environment, showing its potential usefulness for improving the efficacy and reliability of restoration silviculture. Specifically, the study objectives were to: (1) assess the effect of a silvicultural treatment on light levels in a riparian understory; (2) use available information from Drever and Lertzman (2001) to predict rates of height growth for planted Douglas-fir regeneration under post-treatment light levels; and (3) assess the suitability of the treatment in meeting the restoration objective of conifer establishment by measuring survival and height growth of regeneration for 2 yr after planting.

Methods

Study Area

Spirit Creek (50°14'N; 126°45'W), located near Sayward on eastern Vancouver Island, British Columbia, flows predominantly east into Big Tree Creek, a tributary of the Salmon River, which in turn flows into the Pacific Ocean at Johnstone Strait. Spirit Creek is a low-gradient stream, with <2% grade in its lower sections and a mean channel width of 9.2 m. The riparian forest relevant to this study previously had a mixed species composition, including Douglas-fir and Sitka spruce (*Picea sitchensis*); it was clear-cut logged to the stream banks between 1946 and 1951 (von Shilling and Buck 1999).

The study area is in the Coastal Western Hemlock biogeoclimatic zone, Very Dry Maritime subzone (CWHxm), and is characterized by warm summers and cool winters (Meidinger and Pojar 1991, Green and Klinka 1994). Elevation is ~ 75 m above sea level and slopes are <5%. Annual precipitation varies between 2000 and 4000 mm, falling mostly as rain (Green and Klinka 1994). The current riparian forest of Spirit Creek is ~ 50-80 m wide and composed primarily of red alder with some bigleaf maple. The canopy is ~ 25 m in height. Sitka spruce, western hemlock (*Tsuga heterophylla*) and Douglas-fir grow sparsely as single trees or in small clumps as co-dominants and rare suppressed individuals (von Schilling and Buck 1999). Salmonberry (*Rubus spectablis*) and, less commonly, red elderberry (*Sambucus racemosa*) dominate the understory, with cover in the shrub layer ranging from 70-95%. The herb layer is sparsely covered with sword fern (*Polystichum munitum*) and mosses.

Silvicultural Treatment

To create canopy gaps for subsequent conifer underplanting, the Steelhead Society Habitat Restoration Corporation created circular openings between 18-20 m in diameter (254-314 m^2) by cutting 18-21 trees. Distances between gap centers was ~20 m, leaving the edges of some only 1 m or so apart and thereby creating a corridor-like opening with wedges of trees between openings. A 5-m buffer of streamside trees was retained to maintain bank stability and provide inputs of nutrients and LWD into Spirit Creek. The shrub layer was cleared by chainsaw immediately after gap creation. Subsequent brushing treatments were conducted in the spring for 2 yr after the initial falling and brushing. The total treatment area on both sides of Spirit Creek was 16 ha.

In spring 2000, clusters of 10-12 large conifer seedlings with a spacing of 2.4 m were planted in each gap. Species composition of the clusters was approximately 70% Douglas-fir, 20% western redcedar (*Thuja plicata*) and 10% grand fir (*Abies grandis*). The mean height for these bare-root, 2-yr old seedlings was 22 cm for Douglas-fir, 45 cm for redcedar and 41 cm for grand fir. Douglas-fir and grand fir seedlings were not browse-protected but western redcedar seedlings were protected with Vexar® tubing.

The rationale behind planting primarily Douglas-fir, rather than more shade-tolerant species such as western redcedar or grand fir, was that the long-term objective of restoring the riparian functions of large conifers could be achieved sooner by the faster growth of this species (Steve Pettit, Steelhead Society Habitat Restoration Corporation, personal communication). This study therefore focuses on Douglas-fir, as it is considerably more uncertain that this shade-intolerant species will survive under a partial canopy than more shade-tolerant species.

Quantifying the Light Environment

Hemispherical photographs capture the geometry and orientation of canopy trees and can be used to quantify photosynthetically active radiation at a given location in the forest (Anderson 1964, Canham 1988, Frazer et al. 2000). These photographs, combined with digital image analysis, offer a robust way to measure light availability and potentially predict the growth of understory trees (Gendron et al. 1998). The use of canopy photographs has become fairly easy and inexpensive with the advent of high-resolution digital photography (Frazer et al. 2001). I used a Minolta X700 camera with a Minolta fish-eye lens (f = 7.5 mm) mounted on a tripod positioned 1.3 m above the ground surface.

For this study, I quantified light availability over the entire growing season using GLA 2.0 light modeling software (Frazer et al. 2000). GLA 2.0 calculates the light available for photosynthesis by integrating the diurnal and seasonal paths of the sun over the growing season, the mix of direct and diffuse solar radiation, and the spatial distribution of the surrounding canopy (Frazer 1999, Frazer et al. 2000). The growing season was set as the period relevant to growth of Douglas-fir and other conifers in this region, mid-April to the end of August (Brix 1993). GLA 2.0 determines an index of light availability in units of percent of full sun, where full sun refers to the light environment of completely open conditions.

Two sets of hemispherical canopy photographs were taken in June 1999 after foliage fully emerged. First, to characterize the light environment in the entire riparian stand, I took a photograph every 30 m (n = 14) along a 420-m transect randomly initiated within the treatment area. Photographs were taken at least 30 m from the stand edge (i.e., the stream bank or edge of upland coniferous forest). These photographs allowed inferences about light over the entire riparian area as well as about height growth of saplings present as advance regeneration throughout the treatment area. Second, to characterize light within the gaps created by the silvicultural treatment, I took a canopy photograph at the center of each of 14 gaps. These systematic photographs allowed inferences about light only in the gaps themselves. I used these gap-centered photographs to predict height growth of Douglas-fir. Both sets of photographs were taken directly before and after the treatments. In 5 gaps, I measured the maximum height of competing shrub vegetation growing directly adjacent to the photograph location.

Light-Growth Responses

The light-growth response used for predictions in this study was determined by sampling 64 young, vigorous trees on fresh, rich sites across a wide gradient of light (Drever and Lertzman 2001). These trees grew in mature second-growth stands, under canopy openings, in clearcuts and in partially harvested areas located in the CWHxm biogeoclimatic subzone of eastern Vancouver Island. Leader increments were measured for the last three to five growing seasons and averaged to estimate rates of recent height growth. Hemispherical canopy photographs taken at breast height in the place where the tree grew were used to estimate light using the procedure described above. The relation between growth and light was calculated by fitting the Michaelis-Menten equation using nonlinear regression to minimize the sum of squared residuals (see Drever and Lertzman (2001) for details). The Michaelis-Menten equation has the following form:

[1] predicted height growth = $(a \times \text{light})/((a/s) + \text{light})$,

where light is the index of whole season light availability (% of full sun), height growth is the mean annual height growth (cm/yr) over the sampled years (1992-1996), a is the asymptote of the function at high light, and s is the slope of the relationship at zero light. In fresh, rich sites, variation in light explained most of the variation in height growth for Douglas-fir saplings ($r_a^2 = 0.81$).

Observed Mortality and Growth of Planted Conifers

In spring 2002, 2 yr after planting, I assessed vigor and measured height growth for all Douglas-fir and grand fir regeneration. Vigor was assessed as (1) alive or dead and (2) by the presence and extent of chlorosis or dead needles. I measured height growth as the distance from the first to the second branch whorl (2001) and the distance between second and third whorls (2000). Western redcedar seedlings were not measured because of difficulties in accurately determining annual growth from leader increments. At this time, the height of competing shrubs was again measured in 5 gaps.

Experimental Design and Statistical Analyses

In this study, all of the gaps were also brushed, making it impossible to separate the effects on regeneration growth from overstory removal from those of brushing. Therefore, the treatment should be considered as both the gap creation *and* brushing. I compared the light levels before and after the silvicultural treatment using paired t-tests. The level of significance was set at $P = 0.05$. No data transformation was necessary.

Results

Pre-treatment Light

Light availability in the riparian stand before the silvicultural treatment was low, with a mean of 16 ± 2% of full sun (± SE). Maximum and minimum values were 29 and 7% of full sun.

Pre-treatment mean light levels at gap centers (14 ± 2% of full sun) were similar to those of the entire stand but showed less variation ($CV_{gaps} = 0.24$ vs. $CV_{stand} = 0.40$). Maximum and minimum values were 20 and 8% of full sun.

Post-treatment Light

The silvicultural treatment significantly increased ($P < 0.001$) mean light levels (26 ± 3% of full sun) in the riparian stand. Maximum and minimum values were 40 and 11% of full sun (Figure 1a). The mean light level at gap centers after treatment was 30 ± 4% full sun, significantly higher than the pre-treatment mean ($P < 0.001$). Maximum and minimum light levels were 51 and 21% of full sun (Figure 1a).

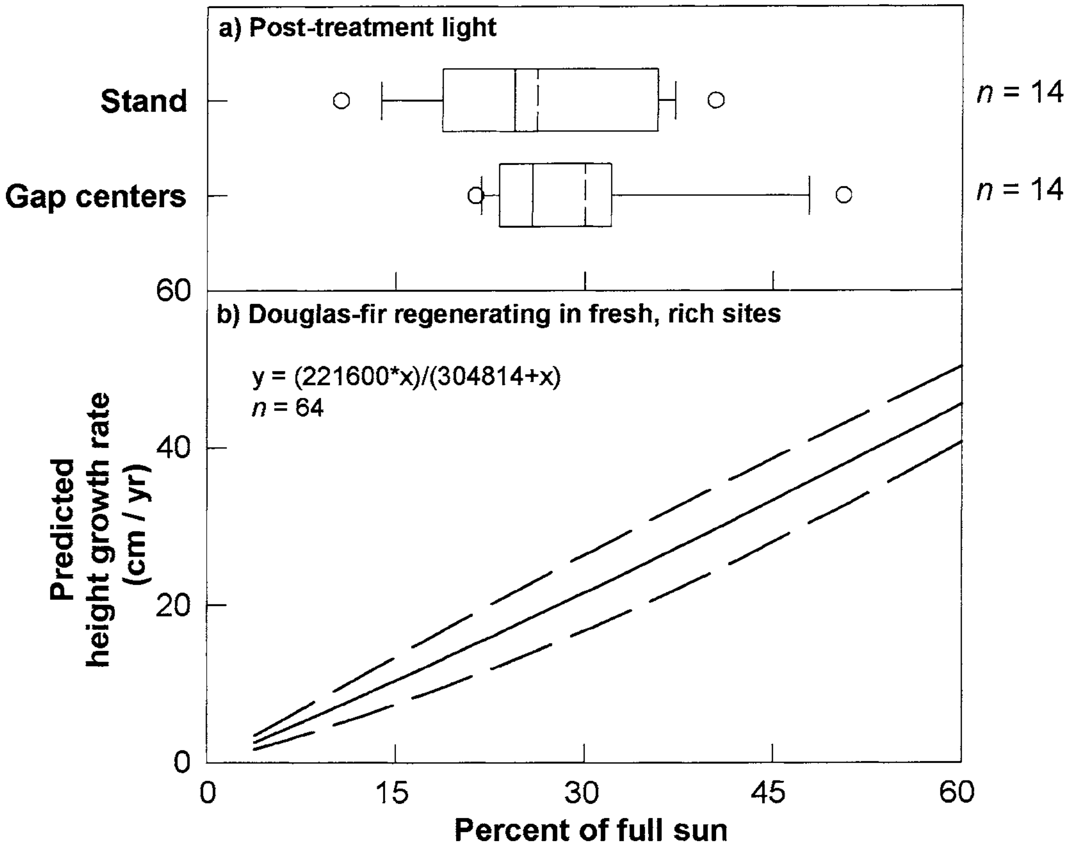

Figure 1. (a) Light levels created by the silvicultural treatment. (b) Predicted height growth for Douglas-fir in fresh, rich sites (adapted from Drever and Lertzman (2001)). Dashed lines indicate 95% CI for the population mean. Box boundaries indicate the 25th and 75th percentiles, the center solid line, the median and the dashed line the mean. Error bars indicate the 10th and 90th percentiles and open circles 5th and 95th percentiles.

Height Growth Predictions

Based on the light-growth response curve reported in Drever and Lertzman (2001), the mean height growth of Douglas-fir growing in fresh, rich sites should be 12 cm/yr at the mean light levels of the pre-treatment stand (Figure 1b). At the mean light level of the post-treatment stand, mean height growth of Douglas-fir seedlings should be 19 cm/yr. Seedlings in the gaps should grow in height with a mean of 22 cm/yr (Figure 1b). No predictions were possible for grand fir as I found no light-growth response curves in the literature.

Observed Mortality and Growth of Planted Conifers

In March 2002, 23 months after planting, Douglas-fir regeneration appeared established and growing well. The mortality rate was 7% after 2 yr, and the mean height of the surviving planted cohort was 56.2 cm, an average increase of ~ 34 cm from the time of planting. Observed mean growth rates were 15.8 cm/yr for 2000 and 17.6 cm/yr for 2001 (Figure 2). Seven Douglas-fir individuals showed no growth for 2000 but some for 2001. All of these individuals had lower growth rates (<11 cm/yr) than predicted from the growth response of Drever and Lertzman (2001) and showed chlorisis or abundant dead needles on lower branches.

Grand fir and western redcedar were also established and growing well. Only one grand fir individual died, and the mean height of the planted cohort was 81.9 cm, an increase of ~ 41 cm from the time of planting. Observed mean growth rates for grand fir were 19.8 cm/yr for both 2000 and 2001. For redcedar seedlings, the mortality rate was 10% after 2 yr. Competing shrub vegetation, almost exclusively salmonberry, had a mean height of 2.4 m in 1999 and 1.4 m in 2002.

Discussion

My results provide evidence that the combination of gap creation and brushing allow survival and growth of planted Douglas-fir seedlings under a partial red alder canopy. Observed mortality in the critical first 2 yr following planting was less than 10%. Mortality of Douglas-fir regenerating in coniferous stands increases with decreasing ambient light, with a sharp increase at light levels below 20% of full sun (Mailly and Kimmins 1997). Since light levels in the gaps were almost

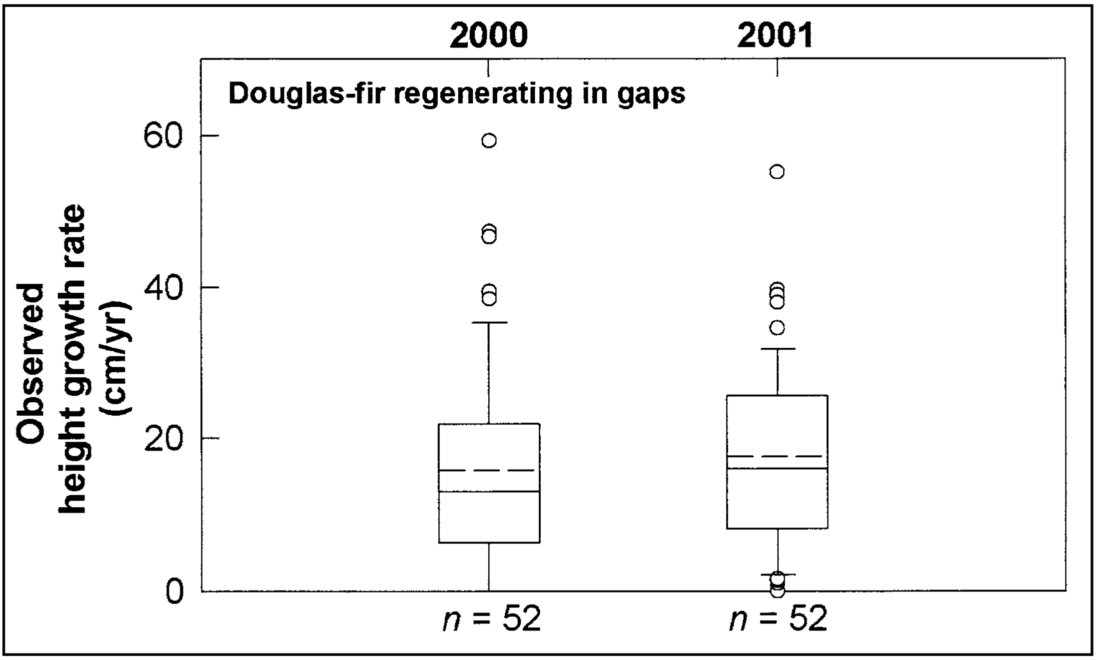

Figure 2. Observed height growth for 2 yr of surviving Douglas-fir in the riparian area of Spirit Creek. Box boundaries indicate the 25th and 75th percentiles, the center solid line, the median and the dashed line the mean. Error bars indicate the 10th and 90th percentiles and open circles 5th and 95th percentiles.

all above the 20% threshold (Figure 1a) and shading of regeneration would occur only during the times of year while the deciduous canopy is in place, it is possible that Douglas-fir mortality will not be a significant future concern. In 2001, Douglas-fir seedlings achieved mean rates of height growth within the 95% CI (16-26 cm/yr) predicted by growth-response curves at 30% of full sun (Figure 2). The individual trees that showed no growth in 2000 but some in 2001 likely suffered planting shock – a period of little to no height growth during which newly transplanted trees focus resources on root growth and nutrient uptake while delaying the initiation of shoot growth (Smith and Walters 1963, Stoneham and Thoday 1985, Kneeshaw et al. 2002).

For this silvicultural treatment, "free-to-grow" status was deemed to occur when trees are 1 m taller than competing vegetation (von Shilling and Buck 1999). Given the mean height of 2.4 m for competing shrubs measured before brushing, free-to-grow status would be obtained when trees reach 3.4 m in height. At the predicted growth rates described above, Douglas-fir regeneration will reach, on average, the same height as competing vegetation after 10 yr and free-to-grow status will be reached after 15 yr. However, at the observed growth rates, these heights will be reached by the Douglas-fir seedlings after 14 and 20 yr. For grand fir, if the seedlings continue growing at observed growth rates, these heights will be reached after 10 and 15 yr. The target age for a free-growing stand in this treatment is 15 yr (von Schilling and Buck 1999). Although somewhat optimistic, this target age seems feasible given the observed reduction of mean height of competing shrubs due to brushing and the strong possibility the rate of annual growth will increase as trees increase in total height, as has been reported for other conifers (Claveau et al. 2002).

The greatest obstacle for a free-growing cohort in this site is likely understory competition from salmonberry. Salmonberry, common throughout the riparian area of Spirit Creek, is an aggressive competitor that tends to increase in height and density after canopy removal (Haeussler et al. 1990). Moreover, salmonberry shows vigorous re-growth after manual brushing by re-sprouting from stem bases and rhizomes. In sites nearby the study area, salmonberry often fully recovers from brushing to pre-treatment height levels within one season (Haeussler et al. 1990). Successful control by manual brushing of salmonberry is possible with 2 or 3 treatments per year for several years (Haeussler et al. 1990). Although brushing of competing vegetation was planned in the spring 2 yr after planting, this treatment may not necessarily guarantee regeneration success. Increasing the frequency or number of brushing treatments will likely prevent salmonberry growth from negating the competitive advantage provided to the planted conifers by creation of canopy gaps.

Although observed height growth was close to predicted growth after 2 yr, two important caveats are necessary in adopting light-growth response curves to predict tree growth. First, growth responses are typically measured from trees regenerating in non-riparian environments. Given that riparian forests are typically richer and wetter than the environments where these growth responses are determined, actual growth rates on this site may differ from predictions in the long term. That said, I based my predictions of Douglas-fir height growth on data from trees that grew on fresh, rich sites in the same biogeoclimatic zone on Vancouver Island (Drever and Lertzman 2001), thereby reducing the variation in growth response to light that can exist across a region and across site types. Second, although light is assumed to be the primary determinant of seedling height growth, variation in growth can result from other factors, including genetics (Lester et al. 1990, St. Clair and Snieko 1999), mycorrhizal associations (Simard et al. 1997), competition from neighboring plants for belowground resources (Vitousek et al. 1982), morphological differences (Chen et al. 1996, Wang et al. 1994), age and size of regeneration (Messier et al. 1999, Duchesneau et al. 2001) and micro-site variation in soil nutrients and moisture (Carter and Klinka 1992, Drever and Lertzman 2001). In this case, the planted trees originated from the same nursery, meaning variation in growth response to light may be reduced as planted trees show less variation than do trees of natural origin (Lester et al. 1990, Coates and Burton 1999).

Hemispherical canopy photographs can be used to determine rates of canopy closure (Frazer et al. 2000) and thereby determine whether additional canopy openings are necessary to sustain conifer growth (Chan et al. 1996). This assessment is important because understory trees tend to increase their light requirement with increasing size (Messier et al. 1999) and rapid closing of the overstory canopy may compromise long-term success of shade intolerant species such as Douglas-fir. In this study, the advanced age of the alder canopy reduced the potential for preclusion of the long-term objective of Douglas-fir establishment. Height growth and crown expansion of red alder decreases dramatically after two decades (Harrington and Curtis 1986, Chan et al. 1996); alder in the study area are well over 20-yr old (von Shilling and Buck 1999) and thus unlikely to rapidly close the newly created canopy gaps. This situation may provide regenerating conifers the opportunity to capitalize on improved conditions for height growth provided by the gaps (Cole and Newton 1986, Puettmann and Hibbs 1996).

Hemispherical canopy photography offers an easy measure of whole growing season light availability. These measurements can provide the basis for survival and growth predictions of conifers, as illustrated here. They can also provide baseline data for understanding the interactions between the size, pattern, and distribution of canopy openings and the understory light environment. Monitoring light, conifer growth, and shrub growth in subsequent years at Spirit Creek and in other riparian restoration projects will allow determination of where the competitive advantage lies for conifers in terms of light-growth response, both relative to canopy closure and competing vegetation. This information would be useful in designing restoration prescriptions that maintain as much canopy cover as possible (and thereby maintain riparian tree function) while allowing establishment and growth of shade-intolerant trees.

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