# Cramer Fish Sciences

# Using Stream Shade and Large Wood Recruitment Simulation Models to Inform Forest Practices Regulations in Idaho

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## Executive Summary

This report provides important information to the state of Idaho's Forest Practices Act Advisory Committee (FPAAC) as they revise rules guiding timber harvest activities in stream protection zones (SPZs) along fish-bearing streams. In it, we provide results of simulation modeling, informed by data collected by the Idaho Department of Lands (IDL), that demonstrate meaningful differences in maximum riparian function provided by riparian stands across the state. We also demonstrate how the response and recovery of riparian function to management can vary. In total, this information helps FPAAC evaluate tradeoffs and identify measures that can provide opportunities for economic timber harvest while remaining protective of aquatic habitat and fish.

This report documents our analyses in a detailed, step-wise manner. We refer the reader to descriptions of objectives, methods, results, and discussions for each phase of our analysis. This level of detail is necessary in order to thoroughly document our analyses. However, these analyses serve to answer a series of very simple questions, information useful to FPAAC's rule revision mission:

*Does the maximum large woody debris recruitment (LWD) and effective shade (shade) provided by riparian stands vary among forest types found across Idaho?*

We found five forest types where maximum stocking levels meaningfully differed. Among these forest types, differences in maximum stocking levels were consistent with differences identified by similar analyses conducted in eastern Washington and on federal lands in Idaho. When we simulated the amount of LWD and shade provided by stands having the highest stocking levels within each of these forest types, we found differences that were consistent with differences in maximum stocking levels among the types. Specifically, the forest type that provided the greatest maximum stocking also provided the greatest average LWD and shade among uncut, thinnable stands; the forest type with the lowest maximum stocking provided the least average LWD and shade among uncut, thinnable stands. These five forest types, listed in order of the

maximum riparian function they provide, are listed as follows:

- North Idaho grand fir-western redcedar (NIGF)
- Central Idaho grand fir-western redcedar (CIGF)
- Western hemlock-subalpine fir (XXWH)
- Southwest Idaho grand fir-western redcedar (SIGF)
- Douglas-fir (XXDF)

These forest types provided the foundation for all the analyses conducted in this report.

*What factors influence the rate of response of LWD and shade to forest management?*

We found that the rate of decrease of LWD and shade and the rate of recovery of shade after active forest management varied by forest type, stream width, initial stocking levels, and, in the case of rate of recovery, the relative stocking trend at the time of harvesting. We found that stands that had higher stocking levels—either due to forest type or initial stocking—were more resilient to tree removal. In these stands, we saw lower LWD and shade loss, for comparable management activities, than in stands where stocking levels were lower. For rule-making, this implies more intensive management activities could be considered for stands with higher pre-harvest stocking levels. We also found that stands along narrower streams were more resilient to tree removal. That is, for the same forest management activity, wider streams generally had greater shade loss than along narrower streams. For rule-making, this implies more intensive management activities could be considered for stands along narrow streams. And, when considering recovery of shade, we found that stands with increasing stocking trends at harvest tended to recover to higher shade levels. That is, younger stands were more resilient—in terms of recovery—than older stands. For rule-making, this implies more intensive management activities could be considered for younger stands.

*"How much" and "how long" are the effects of forest management on riparian function?*

We found that the effects of forest management increased with increased clearing of riparian buffers and with increased thinning intensity. But, the extent of this effect varies according to the factors introduced above. Riparian buffer configuration is an important factor, too. Generally, when thinning throughout a 50 ft riparian buffer, the effects of forest management are least in stands with higher stocking—either due to forest type or to higher initial stocking levels—along narrower streams. In these instances, greater removal of trees can occur, to achieve the same shade loss, than could occur along wider streams or in stands with lower levels of stocking. In comparison, when we employ a stream-adjacent 25 ft no harvest zone along with an outer 25 ft harvest buffer, we see that the effects of forest management on shade are greatly reduced. Shade reduction is limited to less than 10% across all forest types, stream widths, initial stocking levels, and stocking trends. Shade recovery is at least 85% of that which would occur without management in all instances. For rule-making, this implies more intensive management activities could be considered when using a no harvest buffer.

*What are the benefits of forest management on riparian function?*

We demonstrate where high levels of shade could be maintained with repeated thinning of stands capable of recovering shade. Without management such stands would naturally "break up", move out of the stem exclusion phase, become older, diverse forests and provide lower levels of shade. We demonstrated the consequence of this management choice—no management of riparian buffers versus strategic thinning to maintain high shade levels—using the IFP data set (see Appendix E). By thinning stands that are providing high levels of shade (e.g., upward trending stands), higher levels of shade can be maintained across the landscape and over time. Without management of these riparian buffers, stands ultimately provide lower levels of shade and, as a consequence, landscape levels of shade decrease. For rule-making, this implies that there are situations where intensive management activities in riparian buffers could provide long-term, landscape-level benefits to riparian function.

It is important to note, however, that this benefit is predicated on being able to treat the entire riparian buffer (e.g., a 50 ft harvest buffer) to generally accepted silvicultural thinning targets (e.g., relative stocking below 55). Thinning to relatively high residual stocking levels (e.g., above a relative stocking of 55) would have a limited benefit. Furthermore, use of a stream-adjacent no harvest zone limits the long-term, landscape-level benefits. Lack of activity in the no harvest buffer could lead to long-term stand conditions—and shade levels—that would be lower than if the stream-adjacent zone were actively managed. Because the no harvest zone has greater influence on riparian function delivered to the stream, the benefits of thinning in the outer buffer zone would have only a slight benefit to long-term, landscape-level shade. For rule-making, this implies that increased management intensity would increase opportunities to realize long-term, landscape-level benefits to stream shade.

*How can this knowledge be applied to develop an implementable rule?*

The answer to this question will depend on the decision made by FPAAC about riparian measures to employ in SPZs. We see one of two general decisions that FPAAC may make. One is that they choose to employ a 50 ft harvest buffer and identify an appropriate target level of reduction in LWD and shade. In this report, we have correlated LWD and shade reduction with reductions in relative stocking. These rates are reported in Appendices C and D. Once FPAAC decides on acceptable levels of LWD and shade reduction, we can determine associated relative stocking reductions by way of these relationships. These levels may vary by forest type, initial stocking level, stream width, and stocking trend—important factors, as described above. Alternatively, FPAAC may choose to employ a 25 ft stream-adjacent no harvest buffer. This could greatly simplify the rules. While rates of reduction and recovery vary by forest type, initial stocking, stream width, and stocking trend, they are practically limited to low levels because of the great influence of the no harvest buffer. Thus, FPAAC could opt for a simpler rule based on residual stocking levels using information in Appendix F.

In either decision, rules would be based on relative stocking—a metric we introduce in

Phase I of our analysis. Relative stocking is based on Curtis' Relative Density (RD)—a density measure commonly used in western forest types. For any stand, relative stocking is calculated as Curtis' RD for the stand divided by the maximum Curtis' RD for the forest type that the stand represents. We chose this formulation because a) Curtis' RD was meaningfully related to LWD and shade response to and recovery from forest management activities and b) FPAAC's desire to have the metric scale from 0 to 100% stocking—hence, relative stocking. Because of this latter quality, relative stocking is comparable to Relative Density Index which is commonly used when describing thinning targets. The manner in which we calculate Curtis' RD also enables us to directly calculate the number of trees that can be removed/retained to achieve a desired relative stocking removal/retention. It is based on tree diameter where larger trees make a greater contribution to relative stocking, than smaller trees. For rule-making, we provide a simple framework for calculating tree removal/retention rates based on the simple relationship afforded by this method of calculating and using Curtis RD.

*What is our confidence in our work product?*

The data and methods used in our analyses are regionally applicable and reliably used by several entities for understanding the consequences of forest management on stand development and riparian function. We used stand development models developed by the US Forest Service that are in wide use throughout Idaho. We used LWD and shade models that have been peer-reviewed and that have been used for similar investigations in Idaho. These models were informed using continuous forest inventory data collected by the Idaho Department of Lands which provide a representative sample of stand conditions from across Idaho on lands that would be affected by rule-making. These data are known to be of high quality. Overall, we are confident that we used the best available information to conduct our analyses. However, numerous assumptions underlie application of the models and results are not validated by independent study even though our findings are consistent with similar investigations. For rule-making, effectiveness monitoring conducted within an adaptive management framework should be considered by FPAAC to validate and refine the models and rules moving forward.

## Introduction

Large woody debris (LWD) and stream water temperature are important habitat features for native fisheries in the Inland Northwest. Large woody debris provides cover and increases hydraulic diversity, habitat complexity, and pools (Bryant 1983; Bisson et al. 1987). Increased water temperatures can affect salmonid physiology, behavior, and distribution, and can interact with other stressors affecting salmonids (US Environmental Protection Agency (US EPA) 2001). Gregory et al. (2003) provides a comprehensive overview of several models that have been used to predict LWD recruitment in managed landscapes. Similarly, several models have been developed to predict stream temperatures in managed landscapes (Beschta and Weatherred 1984, Theurer et al. 1984, Brown and Barnwell 1987, Doughty et al. 1991, Boyd 1996, Chen et al. 1998, and Chapra and Pelletier 2004). Use of such models to evaluate the effects of forest management on LWD recruitment and stream shade has been important for deciding how to meet multiple objectives through active management.

In Idaho, the Forest Practices Act Advisory Committee (FPAAC) has been working in conjunction with forest industry representatives, Idaho Department of Environmental Quality (IDEQ), and the US Environmental Protection Agency (EPA) to revise rules guiding timber harvest activities in stream management zones along fish-bearing streams (hereafter referred to as the “SPZ rules”). In revising the SPZ rules, FPAAC is responding to Forest Practices Water Quality audits conducted by the IDEQ which cited the need to better quantify rules through use of research that is directly applicable in Idaho. To this end, the Idaho Department of Lands (IDL) has conducted several research projects in support of the Idaho Forestry Program (IFP), a separate but related initiative which involves voluntary riparian measures specific to central Idaho that allow for incidental take of local fish species listed as threatened or endangered under the Endangered Species Act. Specifically, through the IFP, IDL has adapted existing quantitative simulation models to evaluate the potential effects of forest management on LWD recruitment and stream shade for forest conditions in north and central Idaho (Teply et al. 2007 and Teply and McGreer 2011).

In this paper, we apply simulation models described in Teply et al. (2007) and Teply and McGreer (2011) to inform potential revisions to the SPZ rules. These models are adapted from the Riparian Aquatic Input Simulator (RAIS) (Welty et al. 2002) and from SHADE (Chen et al. 1998) to simulate the effects of forest management on LWD recruitment and effective shade. SPZ rule revisions considered by the FPAAC included those that vary buffer widths and thinning intensities. Also considered by the FPAAC were levels of commodity production associated with the revised SPZ rules. We conducted our simulations using stand conditions observed on randomly located continuous forest inventory (CFI) plots maintained by IDL on endowment lands they manage in Idaho. Stand conditions encountered on these plots are generally representative of those found on state and private lands regulated by the SPZ rules. Overall, this information helped FPAAC evaluate tradeoffs and identify measures (i.e., SPZ rules) that can provide opportunities for economic timber harvest while remaining protective of aquatic habitat and fish.

This evaluation involved three interrelated activities—reported as “Phases”— addressed independently in this paper. First, we report on the determination of forest types among which the maximum potential stocking and the response for LWD and shade to reduced stocking could differ (Phase I). For each forest type, we then report on the simulated response of LWD recruitment and effective shade to reductions in riparian buffer width and to decreases in relative stocking from thinning activities (Phase II). Finally, we use our findings to develop a framework for revised SPZ rules (Phase III). In using simulation models, we provide a) an effective framework for integrating existing knowledge about the influence of forest management on aquatic habitat, b) a transparent tool for making meaningful comparisons about the relative effects of increasing management activity on aquatic habitat, and c) testable hypotheses that can be evaluated through effectiveness monitoring. Conducted within an adaptive management framework, this effort directly addresses the need to better quantify rules through use of applied research, and it provides a basis for intentional learning which is focused on critical uncertainties and can lead to further improvement of SPZ rules.

## **Phase I: Determine Forest Types**

*Objectives*

Our objective was to identify forest types in Idaho where maximum stocking levels meaningfully differ. Our hypothesis was that such differences could influence the maximum LWD and shade that could be provided by riparian forests, and also influence the rate at which LWD and shade might respond to forest management activities. This hypothesis would be evaluated in Phase II; findings from Phase I provided the basis for this evaluation. Several studies in the region describe very broad differences in forest types in the Inland Northwest (e.g., Kuchler 1964, Bailey and Hogg 1986, and Losensky 1994). We refined these types by evaluating maximum size-density relationships. The foundation for maximum size-density relationships was introduced by Reineke (1933) and models described by Drew and Flewelling (1979) and Curtis (1982). These models are useful for expressing maximum stocking across a range of average tree sizes. Cochran et al. (1984) developed relationships for neighboring forests in southeastern Washington and northeastern Oregon. Similar models are under development by the Intermountain Forest Tree Nutrition Cooperative for Idaho and western Montana; however, their focus is to detect fine scale differences and evaluate the effects of forest management. In comparison to these other efforts, our objective was to identify coarse scale differences in maximum stocking levels that we could carry forward to Phase II.

*Methods*

We evaluated maximum size-density relationships using IDL CFI data. The IDL CFI data set is a system of permanent plots randomly located across forested endowment lands managed by the IDL. These represent the best available data that reliably and consistently characterize stand conditions affected by FPAAC rule-making. We evaluated maximum size-density relationships in ‘uncut’ stands—stands identified in the field as not having active forest management during the current rotation. (See Figure 1 for the spatial distribution of these plots within north, central, and southwest Idaho.) The

IDL CFI measures trees within a stand using variable-radius angle-gage cruise on three sub-plots (basal area factor 20). We combined sub-plot information to characterize conditions at the stand-level. Key stand-level information recorded by the IDL CFI includes latitude and longitude, elevation, slope, aspect, and habitat type (per Steele et al. 1981 or Cooper et al. 1987). Key tree-level information includes species, diameter at breast height (DBH), total height (THT), and live crown percent.

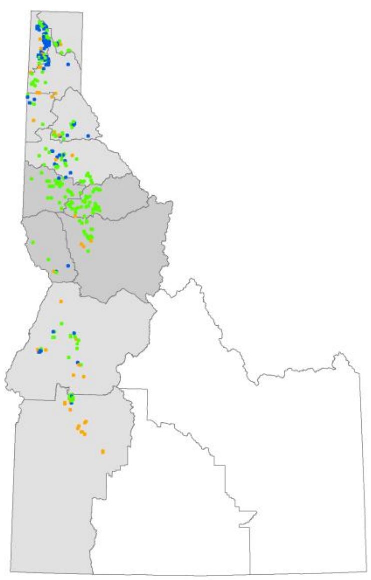


Figure 1. Geographic distribution of uncut Idaho Department of Lands Continuous Forest Inventory plots by habitat type group (green – grand-fir western redcedar; blue – western hemlock-subalpine fir; and, orange – Douglas-fir).

We used stand-level summaries from the IDL CFI data set to fit the log-log model in Reineke (1933) which is used to express the maximum size-density relationship:

(1) $\ln TPA = a + b \ln QMD$,

where *TPA* is trees per acre of trees greater than 3 inches DBH (i.e., pole-sized trees and greater), and *QMD* is the quadratic mean diameter of trees greater than 3 inches DBH. This model was used by Reineke (1933) to formulate a Stand Density Index (SDI). Curtis (1982) used equation (1) as a starting point to formulate Curtis' Relative Density (RD). Curtis (2010) points out that both metrics are nearly equivalent and differ only by a scale factor and a small difference in the slope. Both metrics were derived for even-aged, single species (Douglas-fir) stands in the Pacific Northwest. Reineke (1933) suggested a single slope coefficient of -1.605 and Curtis (1982) suggested an equivalent expression with a slope of -1.5. Cochran et al. (1994) cited evidence that suggested that the slope and intercept may vary due to geographic location, plant association, and perhaps other factors. We determined that it was important to evaluate potential differences in the slope of the maximum size-density line, as well.

We evaluated potential differences in maximum size-density relationships based on 1) geographic location, 2) plant association, and 3) unevenagedness (e.g., departure from a normal, bell-shaped diameter distribution). Potential differences in vegetation conditions across Idaho are well-established by several investigations (e.g., Kuchler 1964, Bailey and Hogg 1986, and Losensky 1994). Practically, we were interested in whether there were any differences among IDL Supervisory Areas. Supervisory Areas are ecologically relevant and are meaningful for administration of the SPZ rules. We considered differences in maximum size-density relationships among three regions defined by groups of Supervisory Areas (north, central, and southwest, as in Figure 1).

Potential differences in plant associations across Idaho are also well-established by several investigations. Habitat types—introduced by Pfister et al. (1977)—are commonly used in the region to describe differences in forest productivity and stand development. Steele et al. (1981) and Cooper et al. (1987) describe habitat types specific to our study area. Practically, we were interested in whether there were any differences among three broad habitat type groups considered by Monserud (1984): Douglas-fir, grand fir-western redcedar, and western hemlock-subalpine fir. Insufficient data existed from other habitat type groups—e.g., Ponderosa pine and lodgepole pine—to conduct a meaningful analysis. Overall, these three habitat type groups covered the super-majority of forest lands regulated under the SPZ rules.

Finally, several investigations have found potential differences in maximum size-density relationships as stands matured. For instance, Sterba and Monserud (1993) and Shaw and Long (2009) observed that as stands developed and became vertically and horizontally diverse, maximum stocking levels decreased. We chose a coarse indicator —presence of pole-sized trees (3 to 8 inches DBH)—as an easily-measured index for this relationship. We found that the presence of pole-sized trees was a reliable indicator of stand conditions that could have higher maximum stocking levels, as suggested by these studies; absence of pole-sized trees indicated stand development stages with potentially lower stocking. Practically, we were interested in whether there were any differences in maximum stocking in stands with poles and in those without.

We evaluated maximum size-density relationships for all combinations of Supervisory Area group, habitat type group, and structural class where sufficient IDL CFI data existed. For each combination, we fit Equation (1) via a step-wise process. In the first step, we fit a model using data from all 'uncut' stands within the subject Supervisory Area group, habitat type group, and structural class combination. In the second step, we fit Equation (1) using data from stands above the regression line we fit in the first step—these represented stands with greater stocking. This regression line would be closer to the maximum compared to that from the first step. In the final step, we inflated the intercept term, *a*, by a value representing the standard error of the prediction. This provided a better representation of the maximum size-density relationship expressed by the data. This was an objective, data-driven approach to parameterizing Equation (1) and it allowed meaningful comparison of maxima among different combinations of Supervisory Area group, habitat type group, and structural class.

Where possible, we aggregated Supervisory Area groups, habitat type groups, and/or structural classes in an effort to simplify the rule-making. If specific combinations provided similar maximum stocking and had similar responses of LWD and shade to forest management, we saw no reason to complicate rule-making with undue complexity. Considerations for aggregation were practical and ecological as much as they were statistical (as discussed further in the Results section). This led to forest types that spanned Supervisory Area groups, habitat type groups, and/or structural classes. Where we did decide to aggregate, we used the same step-wise process described above to fit Equation (1); when doing so, we considered all data within the aggregated forest type to generate final coefficients for Equation (1).

*Results*

We identified five forest types where maximum stocking levels meaningfully differ as measured by the maximum-size density relationships (see Figure 2, Table 1, and Appendix A). Although there are similarities among several of these forest types, we intentionally chose to maintain ecological differences inherent among the habitat type groups. We did not want to lose the opportunity in Phase II to evaluate whether habitat type groups could account for ecologically meaningful differences in the response of LWD and shade to forest management. We found differences in maximum size-density relationships within only one of these habitat type groups—grand fir-western redcedar—where there were differences among maxima in the north, central, and southwest regions. We found no differences among maxima in stands with pole-sized trees and those without. Stand structural class explains the location of a stand along maximum size-density lines; however, there was no statistical basis to claim differences in the maximum stocking levels. We carried these five types forward to Phase II.

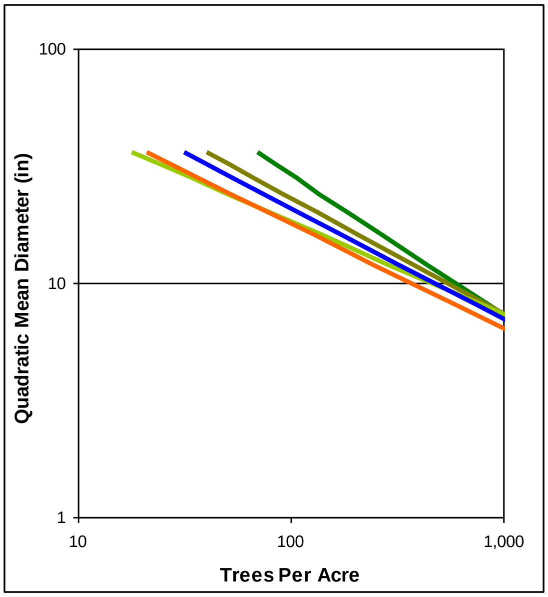



Figure 2. Comparison of theoretical maximum size-density relationships among forest types derived from IDL CFI plots (green – north Idaho grand-fir western redcedar; olive – central Idaho grand-fir western redcedar; lime – south Idaho grand-fir western redcedar; blue – western hemlock-subalpine fir; and, orange – Douglas-fir).

Table 1. Maximum size-density relationships and theoretical maxima derived from IDL CFI plots for forest types in western Idaho.

| Forest Type | Maximum Size-Density Coefficients | | Theoretical Maxima | | |
|---|---|---|---|---|---|
| | a | b | SDI | BA | $RD_{sum}$ |
| North Idaho grand fir-western redcedar (NIGF) | 9.867 | -1.673 | 593 | 323 | 82.3 |
| Central Idaho grand fir-western redcedar (CIGF) | 10.603 | -2.032 | 543 | 296 | 70.6 |
| Southwest Idaho grand fir-western redcedar (SIGF) | 11.577 | -2.523 | 457 | 250 | 58.8 |
| Western hemlock-subalpine fir (XXWH) | 10.645 | -2.114 | 471 | 257 | 64.7 |
| Douglas-fir (XXDF) | 10.688 | -2.239 | 368 | 201 | 52.9 |

Table 1 also reports the associated theoretical maximum stocking for each forest type. Theoretical maxima are scaled from self-thinning maxima; self-thinning maxima are calculated directly from maximum size-density relationship coefficients. The self-thinning SDI is, by definition, the TPA stocking of a stand with a QMD of 10 inches DBH; this is calculated using Equation (1) and the parameters reported in Table 1. The self-thinning maximum basal area is calculated directly from SDI by multiplying the SDI value by 0.5454154 (the basal area of a 10-inch DBH tree). Theoretical maxima are then calculated by dividing the self-thinning values by 0.85. This scalar represents the proportion of the theoretical maximum density where stands reach self-thinning levels (see Keyser 2008a, 2008b). Theoretical maximum SDI and basal area values are useful for interpretation of results and they are used in Phase II FVS simulations.

Table 1 also reports a maximum $RD_{sum}$ for each forest type. $RD_{sum}$ is a relative density metric calculated via the following equation in Curtis (2010):

(2) $RD_{sum} = 0.00545415 * \sum (d_i^{1.5})$,

where $d_i$ is the diameter of an individual tree, and summation is over all trees per acre in the stand that are larger than some specified minimum diameter. $RD_{sum}$ is the summation form of Curtis' Relative Density (RD). Curtis (2010) observed $RD_{sum}$ to be less influenced by departures from the even-aged condition; such conditions are common in Idaho forest types. It is also simpler computationally—a potential added benefit for rule-making. In our case, we summed all trees over 8 inches DBH following Curtis (2010). Self-thinning $RD_{sum}$ maxima were determined from the 90$^{th}$ percentile of values within each forest type. Theoretical maxima are then calculated by dividing the self-thinning values by 0.85, as we did for SDI and basal area. We can use the $RD_{sum}$ maxima reported in Table 1 to calculate the relative stocking of a stand:

(3) Relative Stocking = $RD_{sum}$ / Maximum $RD_{sum}$,

where $RD_{sum}$ is calculated according to equation (2) for any given stand and Maximum

$RD_{sum}$ is reported in Table 1. We use "relative stocking" in Phase II to evaluate the relationship of LWD and shade to stocking levels—both those occurring naturally and those resulting from forest management activities. Calculated in this manner, relative stocking ranges from 0 to 100 within each forest type.

*Discussion*

Generally, maximum stocking levels among forest types followed an ecologically meaningful gradient that is consistent with findings in neighboring regions. We found the greatest stocking levels among uncut plots in the north Idaho grand fir-western redcedar forest type. We observed progressively lower maximum stocking among uncut plots in the central Idaho grand fir-western redcedar type, western hemlock-subalpine fir type, and southwest Idaho grand fir-western redcedar type; the lowest maximum stocking occurred among uncut plots in the Douglas-fir forest type. The maximum SDI values among forest types follow similar trends, as reported by Powell et al. (1999) for southeast Washington and northeast Oregon, and by Wykoff et al. (1982) for federal lands in Idaho. Generally, these trends correlate with differences in soils, temperature, and precipitation as they influence forest production (see Steele et al. 1981 and Cooper et al. 1987). Maximum SDI values reported in Table 1 are intermediate between those reported by Powell et al. (1999) and Wykoff et al. (1982). This is plausible given the relative location of IDL CFI plots, which tend to be located in areas with intermediate temperature and precipitation levels compared to regions covered by these neighboring studies. Correlate habitat types described by Powell et al. (1999)—found in regions where conditions are typically drier—are generally less productive than those in the IDL CFI data set. Conversely, correlate habitat types found on federal lands described by Wykoff et al. (1982)—where conditions are more moist and warm—are generally more productive than those in the IDL CFI data set. Overall, we found the forest types reported in Table 1 to be meaningful and carried them forward to Phase II.

**Phase II: Evaluate Response of LWD and Shade**

*Objectives*

Our objectives were to a) determine the average LWD and shade provided by stands within each forest type, b) determine the rate of decrease of LWD and shade in response to active forest management, and c) determine the rate of recovery of shade after active forest management. Our hypothesis was that forest types could explain differences in maximum LWD and shade that could be provided, as well as the rate at which they might respond to forest management activities. Along with forest types, we were also interested in the potential influence of riparian buffer width, stream width, initial stocking, and stocking trends. Overall, our objective was to identify coarse scale factors accounting for differences in potential riparian function, response, and recovery that we could carry forward to Phase III. Information developed in Phase II is also valuable to the FPAAC for evaluating tradeoffs in commodity production and habitat conservation (i.e., SPZ rule-making).

*Methods*

We conducted our evaluations using the IDL CFI data that we used to fit the maximum size-density relationships reported for each forest type in Phase I. These data represent a range of TPA and QMD combinations (see Appendix A), and represent plots with the highest stocking levels encountered within in each forest type. We selected stands that had initial relative stocking levels greater than 55%; this level of stocking is generally considered in the “zone of competition-induced mortality”—as described by Drew and Flewelling (1979)—where thinning activities would be appropriate under stand density management guidelines. Practically, they represent stand conditions likely to be selected for thinning. Therefore, they represent a meaningful data set for evaluating the effect of SPZ rules considered by FPAAC. No attempt was made to optimize selection of stands, as this would be heavily dependent on landowner objectives and constraints; this was outside the scope of our evaluations.

We used the Forest Vegetation Simulator (FVS) (Keyser 2008a, 2008b) to simulate stand conditions over a 30-year period. FVS was informed using stand-level information recorded by the IDL CFI that included elevation, slope, aspect, and habitat type (Steele et al. 1981 or Cooper et al. 1987). We also carried forward maximum SDI values derived from the maximum size-density relationships for each forest type (Table 1); this was important since maximum SDI is a key determinant of density-dependent mortality which, in turn, affects LWD and shade. Tree-level data were aggregated to the stand-level. Tree records include species, DBH, total height, and live crown percent. Stands in the north and central region were simulated using the North Idaho/Inland Empire variant of FVS; those in the southwest region were simulated using the Central Idaho variant. We used the ThinRDen keyword to harvest stands to progressively lower Relative Density levels (from RD 80 to 20 in increments of 10) via uniform thinning of all trees greater than 8 inches DBH. We calculated relative stocking for all stand conditions following Equation (3). This provided a range of removal levels and residual stand conditions from which we could evaluate the response of LWD and shade.

Examples of stand conditions associated with increasing levels of harvest activity within each forest type can be found in Appendix B. For each forest type, we show unharvested stands with an initial relative stocking (calculated using Equation (3)) greater than 55%, post-harvest conditions after stands were thinned to relative stocking levels of about 40% to 55%, and post-harvest conditions with thinning to relative stocking of 25% to 35% relative stocking. We chose these ranges for demonstration purposes as they reflect general interpretations of relative density offered by Drew and Flewelling (1979). Our relative stocking metric is nearly equivalent to relative density in Drew and Flewelling (1979), and these thresholds are nearly equivalent to similar interpretations of other comparable metrics (e.g., Long and Daniel 1990, Long and Shaw 2005). Thus, 25% to 35% relative stocking generally reflects the lower limit of full site occupancy, 40% to 55% generally reflects common target thinning levels (growth per area is relatively unaffected because residual trees grow faster and competition induced mortality is avoided), and relative stocking greater than 55% reflects the zone of competition-induced mortality. These examples are useful references.

LWD and shade were simulated based on the stand conditions predicted by FVS. We refer the reader to detailed descriptions of methods underlying the LWD and shade simulations in Teply et al. (2007) and Teply and McGreer (2011), and to descriptions of the adapted models in Welty et al. (2002) and Chen et al. (1998). Briefly, the LWD simulation uses a wood budgeting approach that accounts for initial wood loading in a stream, LWD recruitment from the adjacent riparian forest, and depletion once delivered to the stream. For our simulation, we assumed the initial wood loading was zero so that we could make comparisons solely on the component of LWD being delivered from the riparian stands from year zero forward. The sole recruitment mechanism we considered was that from competition-induced mortality. Tree-level mortality was predicted by FVS and is heavily influenced by the maximum SDI. Delivery to the stream was dependent on tree size and distance to the stream. For modeling purposes, we assumed uniform distribution and removal of trees within each stand. Site-level practices can be used to favor LWD and shade; these were not modeled but are addressed in Phase III. The key parameter of interest to the FPAAC was the number of pieces of instream LWD remaining after 30 yrs.

Shade simulation uses a solar path approach to account for effective shade, defined as the percent of solar radiation blocked by vegetation, topography, and reflectance. For our simulation, we assumed no topographic shade and that riparian stands were immediately adjacent to the stream. For any given buffer width, shade provided by riparian vegetation is predicted based on vegetation height, canopy cover, and branch overhang. Vegetation height was calculated from the projected stand conditions and expressed as the average tree height. Canopy cover was reported in FVS simulation output as non-overlapping canopy cover. Branch overhang was assumed to be 10 percent of the vegetation height, following the assumption employed by Chen et al. (1998). Effective shade is also influenced by physical conditions. We simulated shade for three stream widths—10 ft, 20 ft, and 30 ft—for a stream azimuth of 45 degrees. Latitudes and longitudes were selected to be representative of each forest type region. We calculated effective shade for August 1, the time of year when stream temperatures are generally highest and most sensitive to shade reductions. The key parameters of interest were effective shade predicted in simulation year 0 after harvesting, and the rate of recovery to pre-harvest conditions. Year 0 post-harvest conditions represent the maximum effect of forest management on shade and rate of recovery represents the duration of this impact on this particular riparian function.

We generated several summaries from our simulations that directly address our objectives stated above. First, we summarized the average LWD and shade provided by stands within each forest type. Second, we summarized the rate of reduction of LWD and shade in response to a) clearing of vegetation to a prescribed riparian buffer width, and b) thinning of trees within these riparian buffers. Finally, we summarized the incremental loss of shade that occurs under several thinning intensities and the time it takes riparian stands to recover shade to pre-harvest levels after clearing and thinning. The first two summaries are useful for identifying coarse scale factors accounting for differences in potential riparian function, response, and recovery that we could carry forward to Phase III. The third summary is valuable to the FPAAC for understanding the effect of several harvest options on LWD and shade.

*Results*

Potential LWD and Shade

Table 2 summarizes the average LWD and shade provided by uncut stands, with initial relative stocking greater than 55%, by forest type. These results reflect riparian inputs from unharvested 100 ft riparian buffers occurring along both sides of the stream. Trends in these averages followed similar trends to those found for maximum size-density relationships in Table 1. We found that the north Idaho grand fir-western redcedar forest type provided the greatest LWD and shade levels; this type also has the greatest theoretical maximum stocking reported in Table 1. Progressively lower unharvested levels of LWD and shade occurred in the central Idaho grand fir-western redcedar type, western hemlock-subalpine fir type, southwest Idaho grand fir-western redcedar type, and the lowest level occurred among uncut plots in the Douglas-fir forest type. This parallels the trend in theoretical maximum stocking levels reported in Table 1. Generally, this summary supports our hypothesis that forest types account for meaningful differences in riparian function provided by stands across Idaho.

Table 2. LWD and effective shade provided by uncut stands in the IDL CFI with relative stocking greater than 55%, unharvested within 100 ft riparian buffers on both sides of the stream, by forest type.

| Forest Type | LWD[1] | | Effective Shade[2] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 10 ft Stream | | 20 ft Stream | | 30 ft Stream | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| NIGF | 111.2 | 69.2 | 94.3% | 1.8% | 80.6% | 7.8% | 66.8% | 8.4% |
| CIGF | 93.0 | 40.3 | 90.4% | 5.2% | 71.4% | 9.8% | 57.5% | 8.8% |
| SIGF | 68.3 | 29.4 | 80.7% | 10.2% | 59.0% | 11.5% | 46.1% | 9.7% |
| XXWH | 94.4 | 44.7 | 83.6% | 13.9% | 66.0% | 16.4% | 52.9% | 14.4% |
| XXDF | 58.0 | 27.7 | 69.7% | 11.1% | 49.0% | 8.8% | 38.4% | 7.0% |

Notes:

1 – Net LWD recruitment at year 30, in pieces per 1,000 ft of stream

2 – Effective shade at year 0, in percent solar blocking

Table 2 also indicates that as stream width increases, average effective shade decreases. This trend is consistent across all forest types. Generally, this reflects the decreasing proportion of the stream covered by shadows cast by the riparian stand. As streams become wider, a smaller portion of the stream will be covered by this shadow. The magnitude of this effect is correlated to trends in maximum stocking levels. We found that the north Idaho grand fir-western redcedar forest type was least affected by stream width. Progressively increasing effects of stream width on shade occurred in the central Idaho grand fir-western redcedar type, western hemlock-subalpine fir type, and southwest Idaho grand fir-western redcedar type; the greatest effect occurred among uncut plots in the Douglas-fir forest type. This suggests a combined effect of forest type and stream width on riparian function. Overall, this result indicates that maximum shade potential is meaningfully influenced by stream width.

<u>Rate of Reduction</u>

Our second objective in this Phase was to determine the rate of decrease of LWD and shade in response to active forest management and, overall, to identify coarse scale factors accounting for differences in response to carry forward to Phase III. To this end, we refer the reader to Appendix C which provides detailed summaries on the rate of reduction of LWD and shade in response to a) clearing of vegetation to a prescribed riparian buffer width, and b) thinning of trees within these riparian buffers. Summaries area compiled for two harvest buffer widths that were of interest to the FPAAC—75 ft and 50 ft. All tables also provide summaries of total volume, LWD, and shade for a 100 ft no-harvest buffer—this represents pre-harvest levels. Reduction due to clearing—to 75 ft and 50 ft—is reported in terms of the ***absolute*** difference from pre-harvest levels. Reduction due to thinning is reported in terms of the ***absolute*** reduction per 1% reduction in relative stocking. By reporting in this manner, we can then calculate removal/retention levels for any thinning intensity—which we do later in this report. This rate is calculated based on comparison of unharvested levels of volume, LWD and shade for each stand, within the appropriate buffer width, and the amounts provided when the riparian buffer is thinned to the lower level of full site occupancy (i.e., 25% to 35%). By dividing this difference by the associated absolute reduction in relative stocking, we yield the rates of reduction reported in Appendix C.

Appendix C summaries compare rates of reduction by forest type, stream width, and initial relative stocking levels. Forest type and stream width were identified *a priori* as part of our study plan. Investigation of initial stocking levels was based on feedback from IDL foresters as they applied revised SPZ rules in the field. We examined average response for stands with lower relative stocking levels (55% to 70%) and higher stocking levels (70% and greater). The value of 70% is midway between the onset of competition-induced mortality (55%) and the self-thinning level (85%). Finer-scale classification of initial stocking is possible, but the available data was not sufficient to fully inform all classes. Thus, the classification we used reflects a tradeoff in trying to address the feedback of IDL foresters given the available data. This classification is carried forward in subsequent summaries in this report section and in Phase III. Overall, Appendix C provides raw information from which FPAAC can derive and evaluate outcomes for multiple harvest regime scenarios. We focus on a select set of management scenarios in our discussion presented later in this section.

To address the question, “what factors account for differences in the response of LWD and shade”, we generated Tables 3 and 4 to compare the ***relative*** reduction of LWD and effective shade as it varies by forest type, stream width, and initial stocking. Relative reduction was calculated compared to pre-harvest levels within the 100 ft buffer. We report on a relative basis because it emphasizes trends that could be masked when compared on an absolute basis. For instance, we could observe that two situations had a 10% reduction in shade for the same management activity. On an absolute basis, this seems comparable; however, when we compare this reduction to maximum levels of shade that could be provided, it could be a different story. This 10% absolute reduction in shade could account for 25% of the potential shade (as is the case for the Douglas-fir type along 30 ft streams) or only 10% of potential shade (north Idaho grand fir-western redcedar, along narrow streams). For the purposes of identifying meaningful factors, such relative differences are in themselves meaningful. The following addresses the importance of these factors based ***relative*** rates.

Of all the factors evaluated, the reduction of riparian buffer width had the greatest influence on relative LWD and shade reduction. Relative loss of LWD is about 5 times greater using a 50 ft buffer compared to loss from clearing to a 75 ft buffer. Relative shade reduction is nearly three times greater when clearing to a 50 ft riparian buffer width. This magnitude of effect is more or less comparable across forest types, stocking levels, and stream widths. This effect is expected and reflects the well-understood increase in influence of the forest canopy as distance to stream decreases. As loss of this canopy occurs, from the outer buffer edge towards the stream, we would expect the loss of riparian function to accelerate, such as we see here.

Table 3. Percent relative reduction of LWD and effective shade as a result of reduction in riparian buffer width and thinning within residual buffers, by forest type, initial stocking 55% to 70%.

| Forest Type | Stream Width | Clear to 75 ft Buffer | | Thin w/in 75 ft Buffer | | Clear to 50 ft Buffer | | Thin w/in 50 ft Buffer | |
|---|---|---|---|---|---|---|---|---|---|
| | | LWD | Shade | LWD | Shade | LWD | Shade | LWD | Shade |
| NIGF | 10 ft | 2.5% | 0.5% | 1.5% | 0.5% | 13.9% | 1.8% | 1.4% | 0.6% |
| | 20 ft | | 2.9% | | 0.9% | | 8.0% | | 1.0% |
| | 30 ft | | 4.0% | | 1.0% | | 10.8% | | 1.0% |
| CIGF | 10 ft | 3.3% | 1.6% | 1.9% | 1.0% | 14.9% | 5.0% | 1.8% | 1.0% |
| | 20 ft | | 4.2% | | 1.1% | | 10.8% | | 1.2% |
| | 30 ft | | 5.3% | | 1.2% | | 12.8% | | 1.2% |
| SIGF | 10 ft | 1.1% | 3.1% | 1.9% | 1.2% | 10.5% | 8.1% | 1.8% | 1.3% |
| | 20 ft | | 5.1% | | 1.3% | | 12.2% | | 1.3% |
| | 30 ft | | 6.0% | | 1.3% | | 13.9% | | 1.3% |
| XXWH | 10 ft | 0.4% | 1.7% | 1.4% | 0.8% | 6.3% | 4.9% | 1.4% | 0.9% |
| | 20 ft | | 3.9% | | 1.0% | | 9.9% | | 1.0% |
| | 30 ft | | 4.9% | | 1.0% | | 12.2% | | 1.0% |
| XXDF | 10 ft | 1.3% | 3.3% | 1.5% | 1.2% | 9.9% | 8.5% | 1.5% | 1.2% |
| | 20 ft | | 5.3% | | 1.3% | | 12.6% | | 1.3% |
| | 30 ft | | 6.2% | | 1.3% | | 14.3% | | 1.3% |

Table 4. Percent relative reduction of LWD and effective shade as a result of reduction in riparian buffer width and thinning within residual buffers, by forest type, initial stocking greater than 70%.

| Forest Type | Stream Width | Clear to 75 ft Buffer | | Thin w/in 75 ft Buffer | | Clear to 50 ft Buffer | | Thin w/in 50 ft Buffer | |
|---|---|---|---|---|---|---|---|---|---|
| | | LWD | Shade | LWD | Shade | LWD | Shade | LWD | Shade |
| NIGF | 10 ft | 2.7% | 0.5% | 1.2% | 0.4% | 14.4% | 1.7% | 1.2% | 0.5% |
| | 20 ft | | 2.0% | | 0.7% | | 5.9% | | 0.8% |
| | 30 ft | | 3.4% | | 0.8% | | 9.2% | | 0.8% |
| CIGF | 10 ft | 3.0% | 0.5% | 1.3% | 0.5% | 15.4% | 1.8% | 1.2% | 0.6% |
| | 20 ft | | 3.3% | | 0.8% | | 8.9% | | 0.8% |
| | 30 ft | | 4.5% | | 0.8% | | 11.3% | | 0.9% |
| SIGF | 10 ft | 1.8% | 0.9% | 1.3% | 0.7% | 11.3% | 3.0% | 1.3% | 0.7% |
| | 20 ft | | 3.6% | | 0.8% | | 9.8% | | 0.8% |
| | 30 ft | | 4.8% | | 0.8% | | 12.1% | | 0.9% |
| XXWH | 10 ft | 1.8% | 0.6% | 1.1% | 0.5% | 13.3% | 1.6% | 1.1% | 0.5% |
| | 20 ft | | 2.4% | | 0.7% | | 7.1% | | 0.7% |
| | 30 ft | | 3.7% | | 0.8% | | 9.9% | | 0.8% |
| XXDF | 10 ft | 1.6% | 2.9% | 1.2% | 1.0% | 11.7% | 8.2% | 1.2% | 1.0% |
| | 20 ft | | 5.1% | | 1.0% | | 12.5% | | 1.0% |
| | 30 ft | | 6.0% | | 1.0% | | 14.2% | | 1.0% |

We found that the relative rate of LWD reduction varied meaningfully by forest type and that it varied meaningfully by initial stocking level. Generally, we found that forest types and stands that carried greater stocking levels had a greater relative loss in LWD recruitment in response to management activities. This trend is strongest when clearing riparian vegetation to a prescribed buffer width. Greater stocking means greater tree removal when clearing; this, in turn, translates to greater loss of potential LWD. This effect is magnified as clearing occurs closer to the stream (this is the effect of riparian buffer width, described above). In comparison, differences were less pronounced when thinning within riparian buffers. Incremental loss of relative stocking through thinning led to more or less equivalent relative losses in LWD across forest types and initial stocking levels. Absolute differences would occur, however.

We found that the relative rate of shade reduction varied meaningfully by forest type and that it varied meaningfully by initial stocking levels. Generally, we found that forest types and stands that had greater stocking levels were more resilient to tree removal. That is, stands that had greater initial stocking had less shade loss compared to that occurring, from the same management activities, in stands with lower initial stocking. Higher levels of stocking have a ‘buffering’ affect on shade loss. The loss of a tree in a highly stocked stand has less effect on light extinction than does the loss of a tree in a lesser stocked stand. At the extreme, in very low stocking, a single tree may represent the only blocking of a solar ray. As stocking increases, more trees exist to block that solar ray and, shade loss would not be as great. This buffering effect was evident when clearing to prescribed riparian buffer width as well as when thinning.

Finally, we found that the rate of shade reduction varied meaningfully by stream width. Generally, stands along narrow streams were more resilient to stocking removal due to clearing. That is, stands along narrow streams had less relative shade loss compared to that occurring in stands along wider streams. This is mostly explained by the degree of influence that a riparian stand has on a narrow stream versus a wider stream. Along narrower streams, riparian stands—even when managed—tend to cast shadows across the entire stream. Furthermore, according to the Shade.xls model, nearly the entire stream width is shaded by branch overhang. Branch overhang has greater weight in Shade.xls and tends to compensate for canopy cover loss. Thus, with along narrower streams, tree removal doesn't generally affect the proportion of the stream shaded (it is likely to remain completely shaded) nor the greater influence of branch overhang. Along wider streams, riparian stands tend to cast shadows over only a portion of the stream and only a fraction of the stream is influenced by branch overhang. Thus, the loss of canopy cover from clearing has a greater relative influence.

Rate of Recovery

Appendix D summarizes rate of shade recovery after active forest management. We summarize the shade loss and rate of recovery for one buffer width that was of interest to the FPAAC—50 ft. Table D-1 reports results where the initial relative stocking is 55% to 70%; Table D-2 reports results for results where initial relative stocking is 70% and greater. Summaries distinguish outcomes in stands where the relative stocking trend under no management was increasing over the 30-year simulation period from results in stands where relative stocking was decreasing. This distinction highlights meaningful differences in stand dynamics. We compiled our summaries over several thinning intensities denoted by residual stocking levels. Relative stocking reduction represents the loss of relative stocking due to thinning. The average absolute reduction in shade from clearing and thinning was relative to shade in an unharvested 100 ft buffer. Shade recovery was based on a comparison of post-harvest shade at years 10 and 30 compared to shade that would be provided by an unharvested stand (100 ft buffer).

We found that the factors which influenced the rate of reduction of LWD and shade had similar influences on the rate of shade recovery. Stands with higher stocking levels—whether due to potential stocking by forest type or initial stocking levels within a forest type—tended to have higher levels of shade recovery. This is, in part, due to the resiliency of such stands to shade loss. It also reflects the greater cumulative contribution of tree growth, post-harvest, to shade by the greater number of trees in stands with greater stocking. Stands along narrower streams also tended to have higher levels of shade recovery--even though canopy cover recovers in the same manner along a narrow stream as it does along a wider stream. This is at least partly due to the lesser influence of branch overhang along wider streams. It also reflects the contribution of shade beyond 50 ft which would have occurred without harvest. Overall, there are many instances where shade recovery within 30 years is near 100%. This is notable given that a harvested 50 ft buffer provides nearly the same shade as an unharvested 100 ft buffer by year 30. Generally, greater recovery levels are found along narrower streams that had relatively higher levels of pre-harvest stocking.

We also found that the stocking trend, at time of harvest, meaningfully influenced the recovery of shade. Generally, we found that stands that had an increasing stocking trend tended to have higher levels of shade recovery compared to stands that had a decreasing stocking trend. To demonstrate this, we used the information in Appendix D to develop simple linear regressions of relative shade recovery at year 30 as predicted by the relative stocking removed by thinning. Generally, we found that either the intercept was lower or the slope of the regression was greater for equations fit to stands with downward stocking trends in each forest type; i.e., less shade recovery. This finding is intuitive, ecologically. It indicates that if relative stocking loss is already occurring in a stand—as will occur once stands pass the stem exclusion phase—the stand is less able to recover shade lost as a consequence of forest management. The lag in recovery in these stands is likely due to lack of recovery in canopy cover. Average height—and branch overhang—are likely relatively less affected.

*Discussion*

We found that forest types explained differences in maximum LWD and shade that could be provided, and the rate at which they might respond to forest management activities. Along with forest types, we also found that riparian buffer width, stream width, and initial stocking could meaningfully influence the response of LWD and shade to forest management activities. The influence of forest type on potential shade is consistent with simulations conducted by the Idaho Department of Environmental

Quality for development of shade targets (Shumar and de Varona 2009). We would expect a similar correlation between forest type and LWD. Since forest type expresses differences in maximum stocking levels across the state, by extension we also expect that different levels of initial stocking within a forest type would have a similar effect. The Program Document developed for the IDL IFP (available at http://www.idl.idaho.gov/eis/eis_index.html) cites several studies that have reported decreasing cumulative LWD and shade contributions from riparian buffers as buffer widths increase. We found this to be the case in our simulations, too. The response of shade to increased stream width is consistent with trends reported by other investigators. Shumar and de Varona (2009) demonstrate that, as stream width increases, decreased effective shade is provided by any given set of stand conditions. We found this to be the case in our simulations, as well. Overall, these coarse scale factors account for differences in potential riparian function, and in response and recovery, which should be considered in rule development.

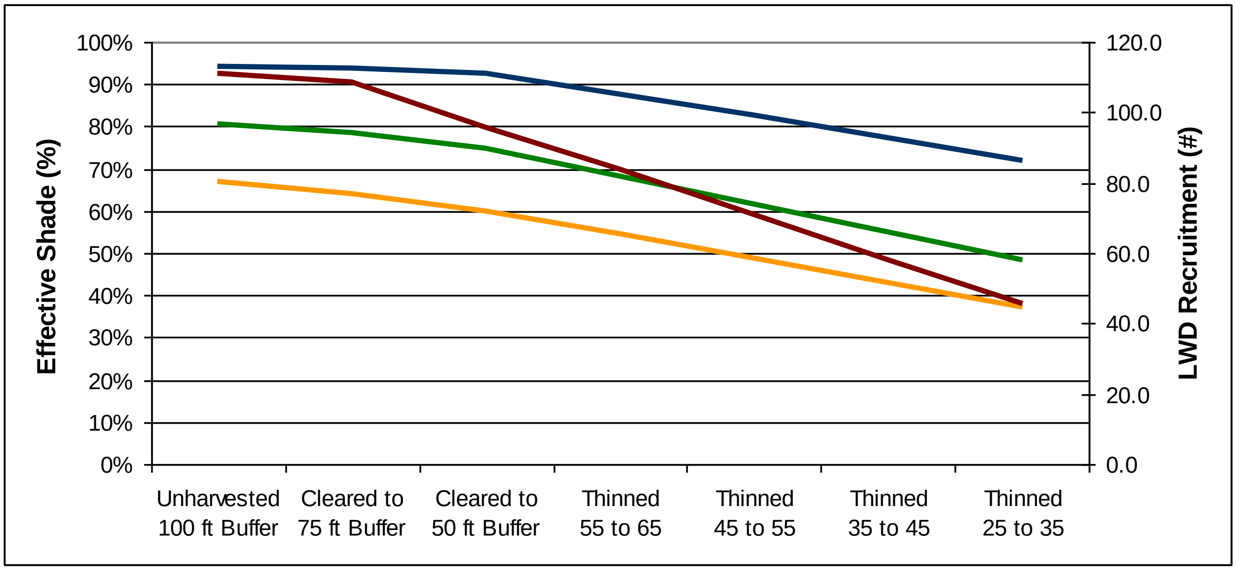
We also found that the rate of shade recovery meaningfully differed depending on the trend in relative stocking at the time of harvest. Upward trending stands had relatively higher levels of shade recovery compared to stands where relative stocking was decreasing. The key difference between these two types of stands was the amount of canopy cover development, post-harvest. This finding is consistent with similar findings we have reported for our work in support of the Idaho Forestry Program (IFP). Teply and McGreer (2011) reports that stands in the stem exclusion phase provide the greatest amount of shade among all stand structural classes. Younger stands provide lower levels of shade, but are presumably increasing in shade as they approach the stem exclusion phase. Older stands provide lower levels of shade, and presumably lost shade as they “broke up” horizontally and vertically from the stem exclusion phase. Our results in this FPAAC report corroborate our findings in our IFP effort. Overall, this coarse scale factor accounts for differences in potential riparian function and in response and recovery that should be considered in rule development.

This finding also indicates the potential benefits of thinning for perpetuating high shade levels across the landscape. Appendix D indicates many instances where thinning in upward trending stands led to recovery of shade to levels practically equivalent to that occurring without management. Theoretically, high levels of shade could be perpetuated with repeated entry (thinning) of these stands. Without management these stands would naturally “break up”, move out of the stem exclusion phase, and provide lower levels of shade. In a separate but related effort, we demonstrated the consequence of this management choice—no management of riparian buffers versus strategic thinning to maintain high shade levels—using the IFP data set (see Appendix E). We showed that, by thinning stands that are providing high levels of shade (e.g., upward trending stands), higher levels of shade can be maintained across the landscape and over time. Without management of these riparian buffers, stands ultimately provide lower levels of shade and, as a consequence, lower levels of shade result over the landscape. The analysis in Appendix E is a proof-of-concept and can be meaningfully refined; however, it is adequate to demonstrate the implications of this management choice. In this regard, it provides valuable insight to FPAAC as they consider tradeoffs between active management and no management of riparian buffers.

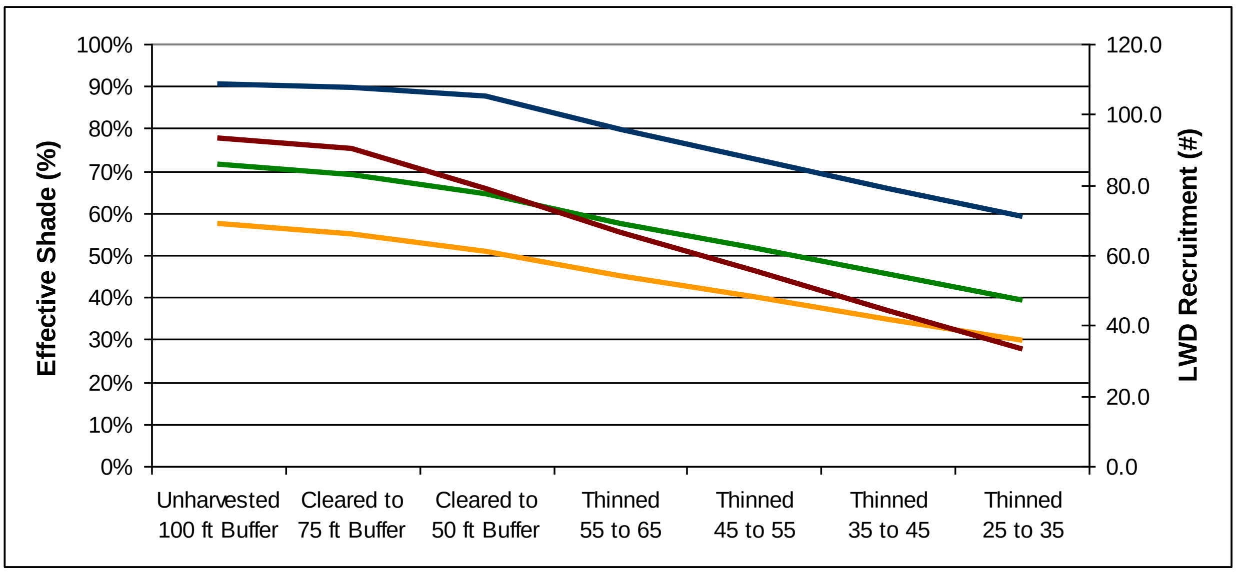
Ultimately, we recognize that FPAAC will be faced with the decision about what level of forest management will be allowed in SPZs. Appendices C and D are valuable to the FPAAC for evaluating tradeoffs in commodity production and habitat conservation. They provide a lot of detail regarding the response of LWD and shade as it varies by forest type, stream width, initial stocking level, and stocking level trend. This is necessary detail. To synthesize the information into a more relevant format for decision-making, we prepared Figure 3 which summarizes the average LWD and shade provided at incrementally increasing levels of forest management activity. We calculated averages for each forest type and stream width (for shade), and integrated these averages across initial stocking levels. Averages are calculated for the unharvested stand condition, riparian buffers cleared to 75 ft and 50 ft, and for residual relative stocking levels when thinning within a 50 ft buffer. This information can help FPAAC consider “how much” LWD and shade reduction may be appropriate.

Figure 3. Average reduction in shade (10 ft stream—blue; 20 ft stream—green; 30 ft stream—orange) and LWD (brown) from clearing and thinning within a 50 ft buffer, by forest type (a through e).

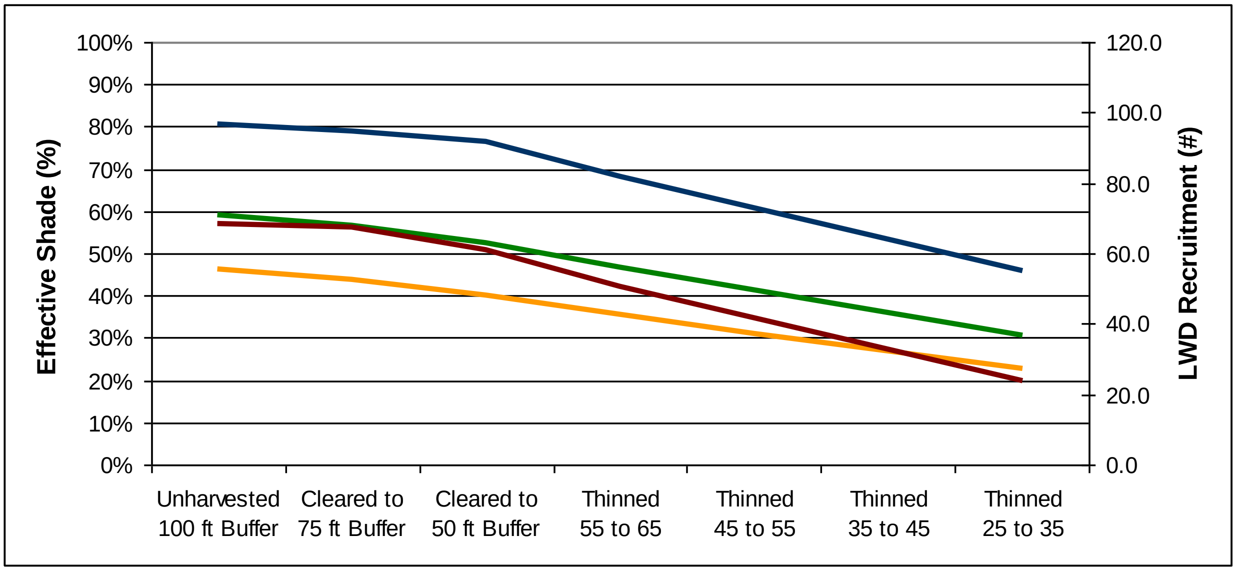
a) North Idaho Grand Fir-Western Redcedar (average unharvested relative stocking is 69.4)



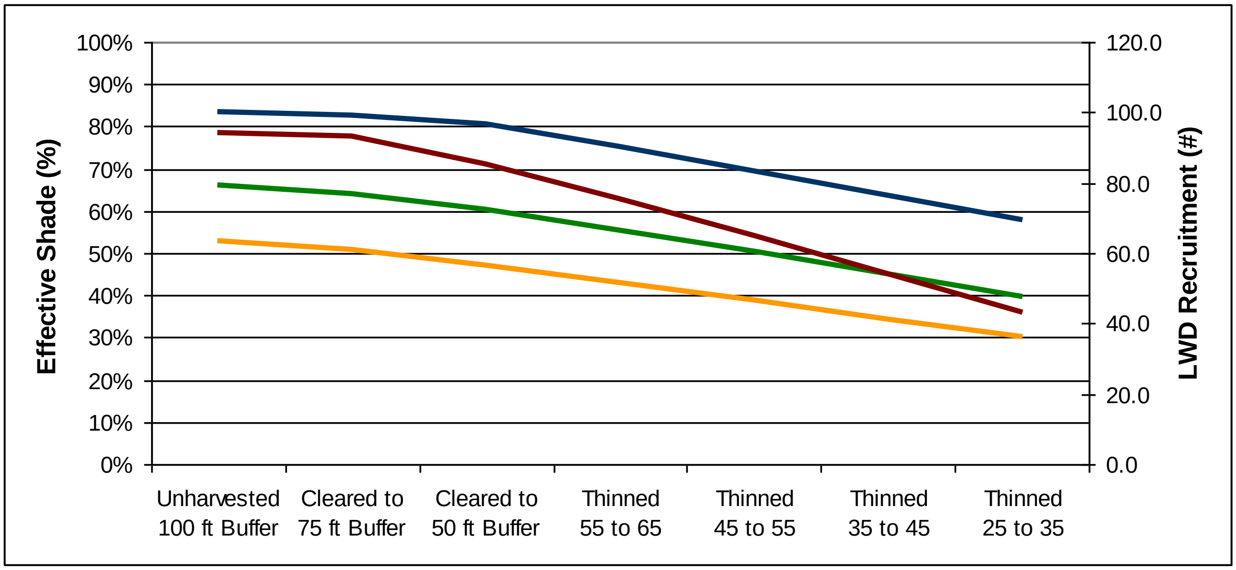

b) Central Idaho Grand Fir-Western Redcedar (average unharvested relative stocking is 71.2)



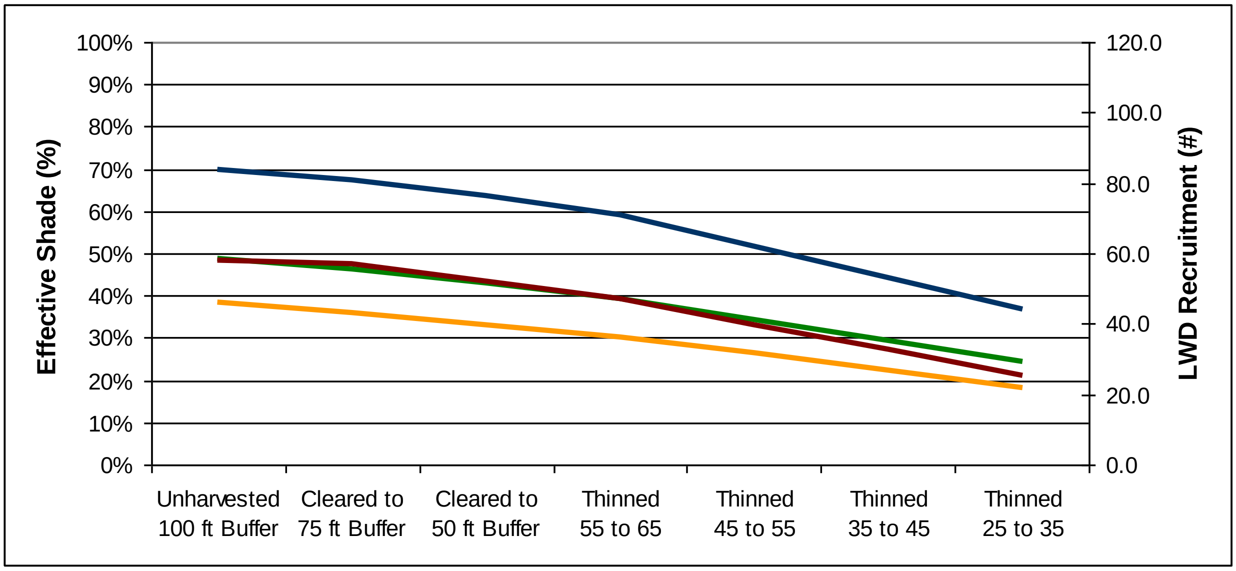
c) South Idaho Grand Fir-Western Redcedar (average unharvested relative stocking is 71.3)




d) Western Hemlock-Subalpine Fir (average unharvested relative stocking is 68.9)



e) Douglas-fir (average unharvested relative stocking is 66.7)



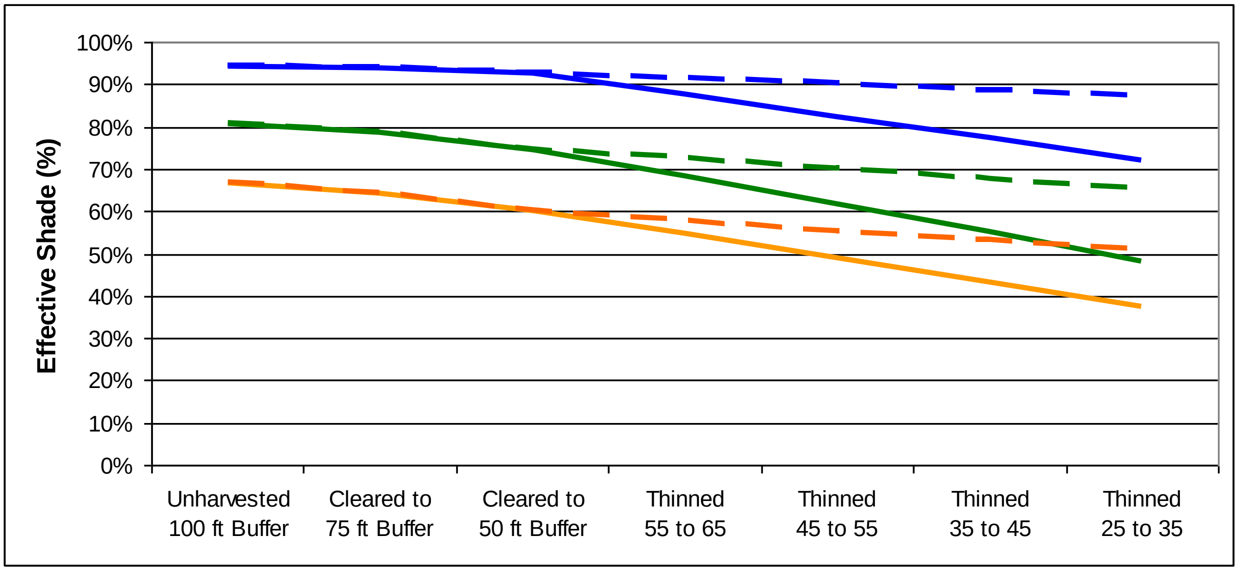

FPAAC will also be concerned with "how long" shade will be reduced in response to forest management activities. Clearing to 75 ft or 50 ft buffer widths will lead to long term reductions in shade, relative to a 100 ft buffer, more or less equivalent to the differences evident in Figure 3. Thinning can have varying effects. In some instances, thinning could perpetuate high shade levels. We found that recovery was greatest along narrower streams where the stocking was greater (either due to forest type or initial stocking levels) and otherwise increasing at time of harvest. In these instances, recovery is rapid—most recovery occurring within 10 years. These high recovery rates can occur even at relatively high thinning rates/low residual stocking levels. In other instances, shade recovery is slower and not as great by year 30. This occurs along wider streams or where stocking is lower or decreasing at time of harvest. These lower recovery rates occur regardless of the thinning intensity. We introduce many reasons for these trends in our presentation of results above. For rule-making, this distinction in stand condition at time of harvest is important when considering "how long".

It is important to note that all of the foregoing analyses are based on thinning regimes which assume that trees will be removed uniformly throughout the riparian buffer. Spatial preference was not simulated. Operationally, we assert that this is likely not the case. In our experience, there are practical limitations to thinning within a narrow riparian strip, especially when the equipment exclusion zone in Idaho extends 75 ft from the stream. More than likely, it will be the choice of an operator to select trees from the outer edge of the riparian buffer zone. This will especially be the case if the number of trees that can be removed is limited. This is due to limitations of logging systems that can be employed, which likely will force hand falling and yarding of trees along the edge. It will be less economical—and may be prohibitive—to remove trees from inside the riparian buffer. It will be very unlikely that trees would be chosen from along the stream edge unless they were of uniquely high economic value, offsetting the costs of extraction. These practical limitations to operating within the 50 ft buffer became evident during the October 2011 FPAAC field trip. Consequently, FPAAC requested an evaluation of shade loss and shade recovery under these practical limitations.

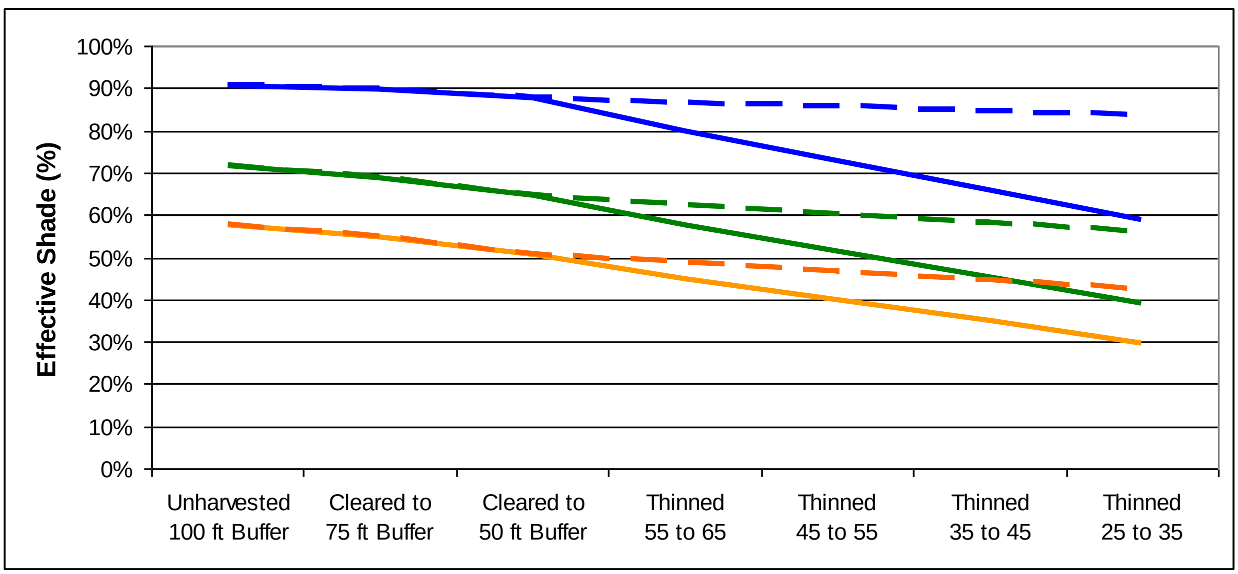
To simulate this, we employed a 25 ft stream-adjacent no harvest zone and an outer 25 ft harvest zone where thinning could occur. Results of these analyses are presented in Appendix F and provide the basis for a direct comparison of shade reduction and recovery using a 50 ft buffer as reported in Appendix D. A comparison is summarized in Figure 4 and Appendix G. Shade reduction is much lower when using a stream-adjacent 25 ft no harvest zone. In all instances, absolute shade loss was less than 10% and often much lower (e.g., along narrower streams with higher levels of relative stocking). This is consistent with our findings during the IFP analysis (Teply and McGreer 2011) where we demonstrated that, using a 25 ft no harvest buffer, shade reduction would be limited to about 10% regardless of thinning intensity. This is due to the relatively greater contribution of the 25 ft no harvest zone to stream shade. It casts the greatest shadow on the stream, it provides greater shade than the outer buffer zone (thus has greater influence in Shade.xls), and it provides shade via branch overhang. In comparison, the outer buffer casts a relatively small shadow on the stream, it contributes very little to shade in Shade.xls, and it does not provide shade via branch overhang; its influence is small. We still see differences due to forest type, initial stocking, and stream width. However, the magnitude of their effect on shade reduction is not as great as their influence when thinning throughout a 50 ft harvest buffer.

Figure 4. Average reduction in shade (10 ft stream—blue; 20 ft stream—green; 30 ft stream—orange) from clearing and thinning throughout a 50 ft buffer (solid line) and using a 25 ft stream adjacent no harvest buffer (dashed line), by forest type (a through e).

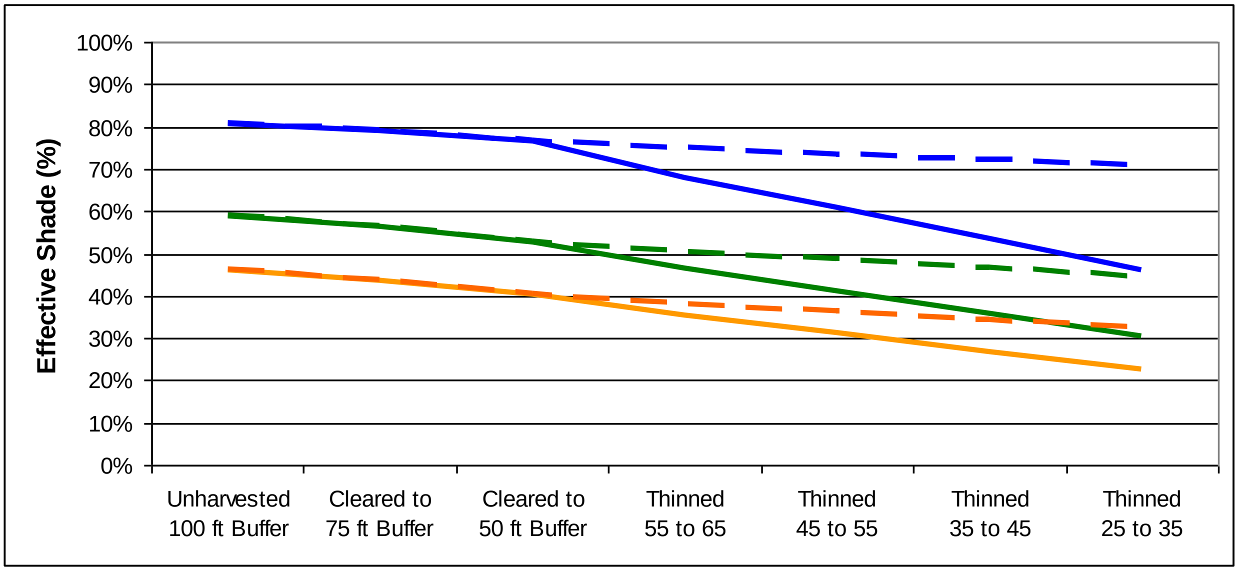
a) North Idaho Grand Fir-Western Redcedar (average unharvested relative stocking is 69.4)



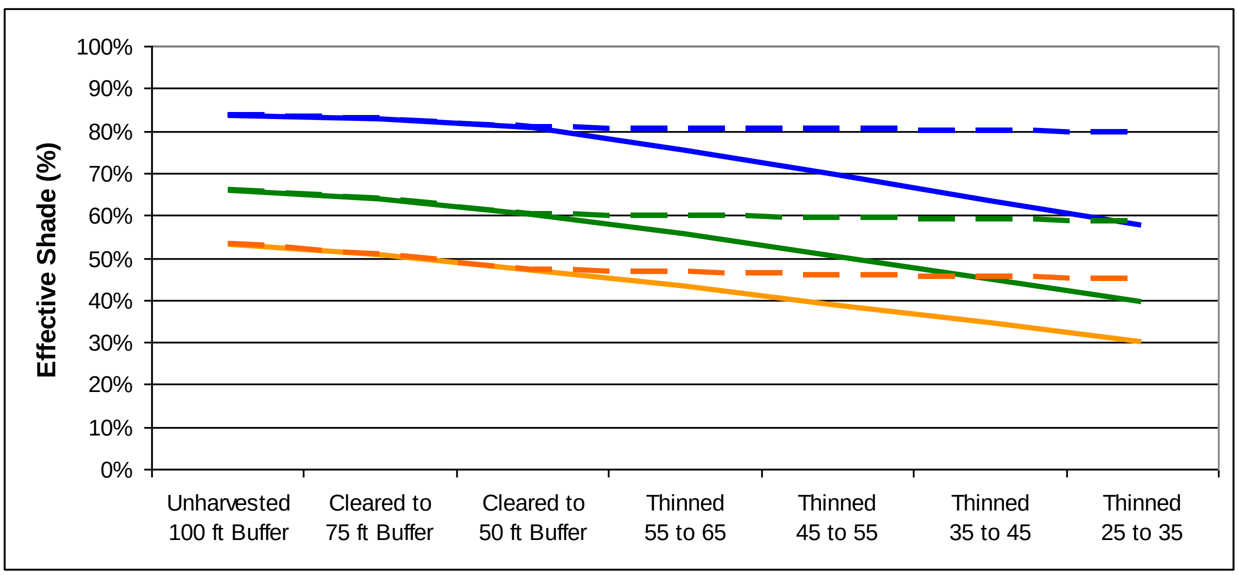

b) Central Idaho Grand Fir-Western Redcedar (average unharvested relative stocking is 71.2)



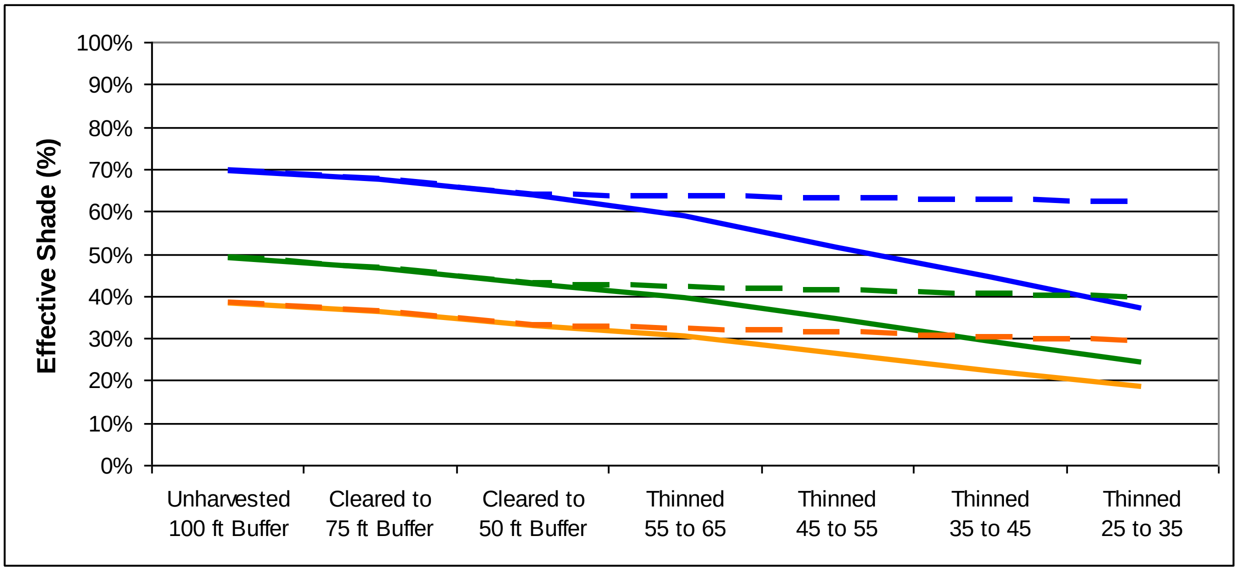
c) South Idaho Grand Fir-Western Redcedar (average unharvested relative stocking is 71.3)




d) Western Hemlock-Subalpine Fir (average unharvested relative stocking is 68.9)



e) Douglas-fir (average unharvested relative stocking is 66.7)




Shade recovery is also greater when using a stream-adjacent 25 ft no harvest zone. Improvements are greatest along wider streams, or where stocking is lower, or where stocking was decreasing at time of harvest. It is also greater where there is greater stocking reduction through thinning. In all instances, average recovery was at least 85% of unharvested levels at years 0 or 30; in many instances recovery was much higher (nearly 100%). As with shade reduction, there are still differences due to forest type, initial stocking, and stream width. However, the magnitude of their effect on shade recovery is not as great as their influence when thinning throughout a 50 ft harvest buffer. We also see the influence of relative stocking trend at the time of harvest; but again, the magnitude of its effect on shade recovery is not as great. These improvements in shade recovery, relative to a 100 ft no harvest buffer, are due to the relative influence of the 25 ft no harvest buffer as described above. And, since it is a no harvest stand condition, the level of shade it provides will be very similar to that provided by a 100 ft buffer that has the same stand condition. Thus, we would expect recovery levels to very close to a no harvested stand condition. Overall, considering the relatively low levels of shade loss, differences in shade recovery are slight. For rule-making, this analysis indicates that spatial preference in tree removal is important to shade loss and shade recovery and it should be considered.

## Phase III: Implementation in the Field

*Objectives*

Our objective was to apply the findings reported in the previous two phases to develop a framework for implementation of revised SPZ rules guiding timber harvest activities in riparian forests. We developed a general approach to cover two possible outcomes of FPAAC rule-making. If FPAAC chooses to employ a 50 ft harvest buffer, then they will likely also be determining the level of reduction in LWD and shade that would be appropriate. In this report, we have correlated LWD and shade reduction with reductions in relative stocking. The slope of this relationship varies meaningfully by forest type, stream width, and initial stocking level as described above. These rates are reported in Appendix C and D. Once FPAAC decides on an acceptable level of reduction in LWD and shade, this can be translated to a ***reduction*** in relative stocking by way of these relationships. If, on the other hand, FPAAC chooses to employ a 25 ft stream-adjacent no harvest buffer, then the rules can be greatly simplified. While rates of reduction and recover vary by forest type, stream width, and initial stocking level, they are practically limited to low levels because of the influence of the no harvest buffer. We would argue that it is simpler to use the information in Appendix F to choose a ***residual*** relative stocking level to assure acceptable shade reduction and recovery.

*Methods*

The determination of the relative stocking to be removed/retained in the field is a three-step process. The first step entails a cruise of the SPZ to characterize the diameter distribution on a trees-per-acre basis. This is often already available from pre-sales cruises. Tallies are needed for all trees 8 inches DBH and greater; 4-inch diameter classes are adequate but 2-inch diameter classes provide better precision. Once cruised, the next step is to determine the number of trees per acre to remove/retain within each diameter class. This requires consideration of silvicultural objectives in regards to the current stand condition. Many post-harvest diameter distributions can be used to achieve the desired removal/retention requirements. The manner in which we determine relative stocking in the field is robust to many different stand conditions and silvicultural prescriptions. Once the number of trees per acre to remove/retain within each diameter class is determined, the final step is to expand these values from a ***per acre*** basis to a ***per reach*** basis. This facilitates operations in the field. The following methods focus on the latter two steps and assume that the forester has cruised the SPZ following traditional forest inventory methods.

The manner in which we calculate relative stocking enables us to directly calculate the number of trees that can be removed or retained to achieve relative stocking-based thresholds—removal or residual. The contribution of any tree to relative stocking can be calculated based on its DBH. Specifically, the contribution of a single tree in the $i^{th}$ diameter class to relative stocking, $RS_i$, is calculated precisely as follows:

(4) $RS_i = (0.00545415 * d_i^{1.5}) / \text{Maximum } RD_{sum}$,

where $d_i$ is the diameter of a tree in the $i^{th}$ diameter class and Maximum $RD_{sum}$ is the theoretical maximum value of $RD_{sum}$—the summation form of Curtis' RD—as reported in Table 1. We determined values for Maximum $RD_{sum}$ for five forest types based on an analysis of the IDL CFI data. These maxima were reported on a per-acre basis and are based on trees 8 inches DBH and greater within a stand. Using Equation 4, we calculated the contribution to relative stocking rate for six diameters (see Table 6). Contribution rates vary by forest type. Forest types that have greater maximum stocking have lower per tree contributions to relative stocking. Conversely, forest types with lower maximum stocking have higher per tree contributions to relative stocking. These differences are meaningful. As shown in Table 6, larger trees make a greater contribution to relative stocking than smaller trees. Thus, many smaller trees can be removed/retained to achieve the same effect as removing/retaining fewer larger trees.

Table 6. Per tree contribution to relative stocking, per acre, by forest type and DBH.

| Forest Type | Per Tree Contribution to Relative Stocking by DBH | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 14 | 18 | 22 | 26 | 30 |
| NIGF | 0.209 | 0.347 | 0.506 | 0.683 | 0.878 | 1.088 |
| CIGF | 0.244 | 0.405 | 0.590 | 0.797 | 1.024 | 1.270 |
| SIGF | 0.293 | 0.486 | 0.708 | 0.957 | 1.229 | 1.524 |
| XXWH | 0.267 | 0.442 | 0.644 | 0.870 | 1.117 | 1.385 |
| XXDF | 0.326 | 0.540 | 0.787 | 1.063 | 1.366 | 1.693 |

These contribution rates are fundamental to the determination the number of trees per acre to remove/retain within each diameter class. This is in itself a two-step process. The first step requires a cumulative tally of relative stocking removed/retained as the forester marks the riparian buffer for thinning by diameter class. The second step occurs when tallying the cumulative relative stocking removed/retained a the point in the foresters prescription-writing when they will need to know how many more trees can be removed/retained to achieve the desired relative stocking level. For instance, as they mark a thin from above, they will reach a point in their cumulative tally where all trees in the next diameter class cannot be marked without exceeding the relative stocking removal threshold. Therefore, they will need to know how many of those trees in that diameter class they can remove. The following examples cover each step.

The following examples demonstrate how cumulative relative stocking removed/retained can be computed using Equation 4 across diameter classes. For demonstration, we use a fictitious stand diameter distribution. For a reduction rule that limits relative stocking reduction to 20% in the central Idaho grand fir-western redcedar type, the relative stocking associated with tree per acre removal by diameter class is tallied:

$RS_i$ for 14 inch DBH: 14 trees per acre * 0.405 relative stocking per tree ≡ 6

$RS_i$ for 18 inch DBH: 20 trees per acre * 0.590 relative stocking per tree ≡ 12

$RS_i$ for 22 inch DBH: 3 trees per acre * 0.797 relative stocking per tree ≡ 2

Cumulative relative stocking removed across diameter classes: 6 + 12 + 2 ≡ 20

The values for relative stocking per tree were interpreted directly from Table 6; they could be calculated directly using Equation 4. For a retention rule that requires a minimum relative stocking of 50% in the central Idaho grand fir-western redcedar type, the relative stocking associated with trees per acre retained by diameter class is tallied:

$RS_i$ for 10 inch DBH: 171 trees per acre * 0.244 relative stocking per tree ≡ 42
$RS_i$ for 14 inch DBH: 20 trees per acre * 0.405 relative stocking per tree ≡ 8
Cumulative relative stocking retained across diameter classes: 42 + 8 ≡ 50

As noted above, when tallying the cumulative relative stocking removed/retained, there will come a point in the foresters prescription-writing when they will need to know how many more trees can be removed/retained in a diameter class to achieve the desired relative stocking level. This can be calculated as a ratio of the incremental amount of relative stocking to be removed/retained to the relative stocking contribution for a single tree in the diameter class being considered. For a removal rule, the number of trees that could be removed in the $i^{th}$ diameter class would be calculated as follows:

(5) $\text{Removal}_i = (\text{Removal RS} / RS_i)$,

where Removal RS is the incremental amount of relative stocking to be removed and $RS_i$ is the relative stocking contribution of a tree in the $i^{th}$ DBH class. Thus, $\text{Removal}_i$ is the number of trees to remove per acre in the $i^{th}$ DBH class to achieve the incremental stocking removal. In developing the first cumulative tally above, we needed to know the number of trees in the 14-inch diameter class that could be removed to meet the 20% relative stocking reduction target. We knew that removal of 18-inch and 22-inch trees resulted in a relative stocking reduction of about 14%; 6% relative stocking removal remained. The number of trees in the 14-inch diameter class that we could remove to achieve an incremental 6% relative stocking removal was calculated as:

5.81 relative stocking removal / 0.405 relative stocking per tree ≡ 14 trees

For a retention rule, the approach is very similar. The number of trees that can be retained in the $i^{th}$ diameter class is calculated as follows:

(6) $Retention_i$ = (Retention RS / $RS_i$),

where Retention RS is the incremental amount of relative stocking to be retained and $RS_i$ is the relative stocking contribution of a tree in the $i^{th}$ DBH class. Thus, $Retention_i$ is the number of trees to retain per acre in the $i^{th}$ DBH class to achieve the incremental stocking removal stocking retention. In our retention example above, we needed to know the number of trees in the 14 inch diameter class that we needed to retain to meet the 50% relative stocking retention target. We knew that retention of 10-inch trees resulted in a relative stocking reduction of about 42%; 8% relative stocking retention remained. The number of 14-inch diameter trees that we needed to retain for an incremental 8% relative stocking retention was calculated:

8.22 relative stocking retention / 0.405 relative stocking per tree ≡ 20 trees

To simplify relative stocking determinations, we developed Table 7 which tabulates the relative stocking contribution, on a per acre basis, of trees in six 4-inch diameter classes. These values were calculated using Equation 4 and expanded to several trees per acre levels. Relative stocking contributions are differentiated by forest type. Values in this table can be used instead of Equation 4; some may find this easier to work with, especially in the field. To demonstrate use of this table, in our removal example above where relative stocking reduction is limited to 20% in the central Idaho grand fir-western redcedar type, the number of trees that can be removed could be tallied as follows:

$RS_i$ for 14 inch DBH for 14 trees per acre: 4.0 + (2 * 0.8) ≡ 6
$RS_i$ for 18 inch DBH for 20 trees per acre: (2 * 5.9) ≡ 12
$RS_i$ for 22 inch DBH for 3 trees per acre: 1.6 + 0.8 ≡ 2
Cumulative relative stocking removed across diameter classes: 6 + 12 + 2 ≡ 20

Values in the calculation were interpreted from Table 7. For instance, for the 14-inch diameter class, we used the value 4.0 to represent 10 trees per acre and the value 0.8 to represent two trees per acre which, when multiplied by 2, represents 4 trees per acre. Ten trees per acre plus 4 trees per acre equals 14 trees per acre. Calculations for the other diameter classes follow the same calculation form.

Table 7. Per tree contribution to relative stocking, per acre, by forest type and DBH.

| Forest Type | TPA | 4-inch Diameter Classes | | | | | |
|---|---|---|---|---|---|---|---|
| | | 8 - 12 | 12 - 16 | 16 – 20 | 20 - 24 | 24 – 28 | 28 - 32 |
| NIGF | 10 | 2.1 | 3.5 | 5.1 | 6.8 | 8.8 | 10.9 |
| | 5 | 1.0 | 1.7 | 2.5 | 3.4 | 4.4 | 5.4 |
| | 3 | 0.6 | 1.0 | 1.5 | 2.1 | 2.6 | 3.3 |
| | 2 | 0.4 | 0.7 | 1.0 | 1.4 | 1.8 | 2.2 |
| | 1 | 0.2 | 0.3 | 0.5 | 0.7 | 0.9 | 1.1 |
| CIGF | 10 | 2.4 | 4.0 | 5.9 | 8.0 | 10.2 | 12.7 |
| | 5 | 1.2 | 2.0 | 3.0 | 4.0 | 5.1 | 6.3 |
| | 3 | 0.7 | 1.2 | 1.8 | 2.4 | 3.1 | 3.8 |
| | 2 | 0.5 | 0.8 | 1.2 | 1.6 | 2.0 | 2.5 |
| | 1 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.3 |
| SIGF | 10 | 2.9 | 4.9 | 7.1 | 9.6 | 12.3 | 15.2 |
| | 5 | 1.5 | 2.4 | 3.5 | 4.8 | 6.1 | 7.6 |
| | 3 | 0.9 | 1.5 | 2.1 | 2.9 | 3.7 | 4.6 |
| | 2 | 0.6 | 1.0 | 1.4 | 1.9 | 2.5 | 3.0 |
| | 1 | 0.3 | 0.5 | 0.7 | 1.0 | 1.2 | 1.5 |
| XXWH | 10 | 2.7 | 4.4 | 6.4 | 8.7 | 11.2 | 13.9 |
| | 5 | 1.3 | 2.2 | 3.2 | 4.3 | 5.6 | 6.9 |
| | 3 | 0.8 | 1.3 | 1.9 | 2.6 | 3.4 | 4.2 |
| | 2 | 0.5 | 0.9 | 1.3 | 1.7 | 2.2 | 2.8 |
| | 1 | 0.3 | 0.4 | 0.6 | 0.9 | 1.1 | 1.4 |
| XXDF | 10 | 3.3 | 5.4 | 7.9 | 10.6 | 13.7 | 16.9 |
| | 5 | 1.6 | 2.7 | 3.9 | 5.3 | 6.8 | 8.5 |
| | 3 | 1.0 | 1.6 | 2.4 | 3.2 | 4.1 | 5.1 |
| | 2 | 0.7 | 1.1 | 1.6 | 2.1 | 2.7 | 3.4 |
| | 1 | 0.3 | 0.5 | 0.8 | 1.1 | 1.4 | 1.7 |

Similarly, we developed Table 8 which tabulates the number of trees per acre necessary to achieve an incremental relative stocking contribution, on a per acre basis, by six 4-inch diameter classes. These values were calculated using Equations 5 and 6, and tabulated for several incremental stocking levels. Values are differentiated by forest type. Values in this table can be used instead of Equations 5 and 6; some may find this easier to work with, especially in the field. All relative stocking values are per acre. To demonstrate use of this table in our retention example, the number of 14-inch trees that we needed to retain for an incremental 9% relative stocking retention was calculated as:

~9% relative stocking retention for 14 inch trees: $12.4 + (2 * 4.9) \equiv 22$ trees

Values in the calculation were interpreted from Table 8. The value 12.4 represents 5% relative stocking and 4.9 represents 2% relative stocking which, when multiplied by 2, represents 4% relative stocking. Five percent plus 4% equals 9%.

Once we determine the number of trees ***per acre*** per DBH class that could be removed or retained, it can be converted to a ***per reach*** basis using an appropriate expansion factor. For instance, if FPAAC decides to permit thinning throughout a 50 ft harvest buffer, the expansion from a per acre basis to one based on a 1,000 ft reach on one side of the stream would be calculated as follows: 50,000 / 43,560 = 1.15. Or, if FPAAC decides to permit thinning only in an outer 25 ft harvest buffer, expansion from a per acre basis to one based on a 1,000 ft reach on one side of the stream is calculated as: 25,000 / 43,560 = 0.57. In this case, 20 trees per acre in the 14-inch DBH class translates to about 12 trees per reach. This final step appears trivial but is important. For computational simplicity, we recommend that foresters make their relative stocking and tree removal/retention determinations on a ***per acre*** basis and then expand to a ***per reach*** basis for given harvest buffer dimensions once these values are known.

*Discussion*

Relative stocking provides a meaningful and convenient means to implement rules that seek to regulate LWD and shade provided by riparian stands in Idaho. Throughout this paper, we have demonstrated meaningful relationships between relative stocking and

Table 8. Trees per acre necessary to achieve an incremental relative stocking, by forest type and DBH.

| Forest Type | Relative Stocking | 4-inch Diameter Classes | | | | | |
|---|---|---|---|---|---|---|---|
| | | 8 - 12 | 12 - 16 | 16 - 20 | 20 - 24 | 24 – 28 | 28 - 32 |
| NIGF | 10 | 47.7 | 28.8 | 19.8 | 14.6 | 11.4 | 9.2 |
| | 5 | 23.9 | 14.4 | 9.9 | 7.3 | 5.7 | 4.6 |
| | 3 | 14.3 | 8.6 | 5.9 | 4.4 | 3.4 | 2.8 |
| | 2 | 9.5 | 5.8 | 4.0 | 2.9 | 2.3 | 1.8 |
| | 1 | 4.8 | 2.9 | 2.0 | 1.5 | 1.1 | 0.9 |
| CIGF | 10 | 40.9 | 24.7 | 16.9 | 12.5 | 9.8 | 7.9 |
| | 5 | 20.5 | 12.4 | 8.5 | 6.3 | 4.9 | 3.9 |
| | 3 | 12.3 | 7.4 | 5.1 | 3.8 | 2.9 | 2.4 |
| | 2 | 8.2 | 4.9 | 3.4 | 2.5 | 2.0 | 1.6 |
| | 1 | 4.1 | 2.5 | 1.7 | 1.3 | 1.0 | 0.8 |
| SIGF | 10 | 34.1 | 20.6 | 14.1 | 10.5 | 8.1 | 6.6 |
| | 5 | 17.1 | 10.3 | 7.1 | 5.2 | 4.1 | 3.3 |
| | 3 | 10.2 | 6.2 | 4.2 | 3.1 | 2.4 | 2.0 |
| | 2 | 6.8 | 4.1 | 2.8 | 2.1 | 1.6 | 1.3 |
| | 1 | 3.4 | 2.1 | 1.4 | 1.0 | 0.8 | 0.7 |
| XXWH | 10 | 37.5 | 22.6 | 15.5 | 11.5 | 8.9 | 7.2 |
| | 5 | 18.8 | 11.3 | 7.8 | 5.7 | 4.5 | 3.6 |
| | 3 | 11.3 | 6.8 | 4.7 | 3.4 | 2.7 | 2.2 |
| | 2 | 7.5 | 4.5 | 3.1 | 2.3 | 1.8 | 1.4 |
| | 1 | 3.8 | 2.3 | 1.6 | 1.1 | 0.9 | 0.7 |
| XXDF | 10 | 30.7 | 18.5 | 12.7 | 9.4 | 7.3 | 5.9 |
| | 5 | 15.3 | 9.3 | 6.4 | 4.7 | 3.7 | 3.0 |
| | 3 | 9.2 | 5.6 | 3.8 | 2.8 | 2.2 | 1.8 |
| | 2 | 6.1 | 3.7 | 2.5 | 1.9 | 1.5 | 1.2 |
| | 1 | 3.1 | 1.9 | 1.3 | 0.9 | 0.7 | 0.6 |

the rate of decrease of LWD and shade in response to active forest management, and the rate of recovery of shade after active forest management. These rates vary by forest type, stream width, initial stocking level, and stocking trend at the time of harvest. The relative stocking metric we introduced in Phase I is fundamental to the entire analysis we present in this report. Furthermore, the manner in which we calculate relative stocking makes it possible to directly calculate the contribution of a single tree to relative stocking based on the tree's DBH. This enables formulation of simple equations and tables, as presented above, to determine not only the relative stocking contribution of a tree, but also the trees per acre needed of a certain diameter to achieve a desired incremental relative stocking removal/retention. .

Other stand-based metrics were explored early in project but deferred in favor of the relative stocking metric. These other metrics included: trees per acre, basal area, average height, average diameter, crown cover, Relative Density Index, Stand Density Index (SDI), and Curtis' Relative Density (RD). These metrics either did not have a strong correlation with LWD and shade response and/or they were considered by the group as too complex for implementation. The relative stocking metric introduced and used throughout has a strong correlation with LWD and shade response and is easy to calculate. Relative stocking is based on Curtis' Relative Density (RD) and the manner in which we calculate it also enables us to directly calculate the number of trees that can be removed/retained to achieve a desired relative stocking removal/retention, as evidenced above. But, at the request of FPAAC, we scale Curtis' RD relative to the maximum Curtis' RD within the stand's forest type. Because of this, relative stocking ranges from 0 to 100% which is convenient as it then correlates with Relative Density Index—the basis for interpretation of stocking levels of thinning, as used above.

But, it is new and for that reason we understand that it may meet resistance. If that is the case, it is our opinion that both Curtis' RD and Stand Density Index are viable alternatives. Curtis (2010) points out great similarity between these two metrics. Relative stocking is based on the summation form of Curtis' relative density. These metrics performed comparably to relative stocking and are established metrics with wide use in the Pacific Northwest. However, they are foreign and can require more field measurement. Nevertheless, they are established metrics and there is much literature and guidance on their measurement and interpretation. The challenge would be introducing these metrics to Idaho foresters for broad use—the same challenge facing use of the relative stocking metric. If FPAAC wishes to revisit use of Curtis' RD or SDI, they can with the understanding that much of the relative stocking-based analysis in this report can be reliably cross-walked. We do not, however, recommend consideration of the other metrics we evaluated as they were found to be considerably less reliable.

## References

Bailey, R.G. and H.C. Hogg. 1986. A world ecoregions map for resource reporting. Environmental Conservation, Vol. 13, No. 3, pp. 195-202.

Beschta, R.L. and J. Weatherred. 1984. A computer model for predicting stream temperatures resulting from the management of streamside vegetation. USDA Forest Service. WSDG-AD-00009.

Boyd, M.S. 1996. Heat Source: stream temperature prediction. Master's Thesis. Departments of Civil and Bioresource Engineering, Oregon State University, Corvallis, Oregon.

Brown, L.C. and Barnwell, T.O. 1987. The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: documentation and user manual. EPA/600/3-87/007, US Environmental Protection Agency, Athens, GA.

Bisson, P., R. Bilby, M. Bryant, C. Dolloff, G. Grette, R. House, M. Murphy, K. Koski, and J. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: Past, present, and future. P. 143–190 in Proc. Streamside management: Fisheries and forestry interactions, Salo, E.O., and T.W. Cundy (eds.). University of Washington, Seattle, WA.

Boyer, K., D. Berg, and S. Gregory. 2003. Riparian management for wood in rivers. P. 407-420 in Proc. of symposium 37, The Ecology and Management of Wood in World Rivers, Gregory, S. et al. (eds.). American Fisheries Society, Bethesda, MD.

Bryant, M. 1983. The role and management of woody debris in west coast salmonid nursery streams. North Am. J. Fish. Manage. 3:322–330.

Chapra, S.C. and G.J Pelletier. 2004. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Chen, Y.D., R.E. Carsel, S.C. McCutcheon, and W.L. Nutter. 1998. Stream temperature simulation of forested riparian areas: I. Watershed-scale model development. Journal of Environmental Engineering 124(4):304-315.

Cochran, P.H., J.M. Geist, D.L. Clemens, R.R. Clausnitzer, and D.C. Powell. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. USDA Forest Service Research Note PNW.RN-513.

Cooper, S.V., K.E. Neiman, R. Steele, and D.W. Roberts. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

Curtis, R.O. 1982. A simple index of stand density for Douglas-fir. Forest Science 28:92-94.

Curtis, R. 2010. Effect of diameter limits and stand structure on relative density indices: A Case Study. Western Journal of Applied Forestry, Volume 25, Number 4, October 2010, pp. 169-175(7)

Doughty, K., J.E. Caldwell, and K. Sullivan. 1991. T/F/W stream temperature method: User's manual. Washington Department of Natural Resources Report TFW-WQ4-91-002.

Drew, T.J. and J.W. Flewelling. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. Forest Science 25:518-532.

Gregory, S., M. Meleason, and D. Sobota. 2003. Modeling the dynamics of wood in streams and rivers. P. 315–336 in Proc. of symposium 37, The Ecology and Management of Wood in World Rivers, Gregory, S. et al. (eds.). American Fisheries Society, Bethesda, MD.

Keyser, Chad E. comp. 2008a (revised July 29, 2010). Central Idaho (CI) variant overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 31p.

Keyser, Chad E., comp. 2008b (revised July 29, 2010). Northern Idaho / Inland Empire (NI/IE) variants overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 49p.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States, American Geographical Society, Special Publication No. 36.

Long, J., and T. Daniel. 1990. Assessment of growing stock in uneven-aged stands. Western Journal of Applied Forestry 5:93-96.

Long, J. and J. Shaw. 2005. A density management diagram for even-aged ponderosa pine stands. Western Journal of Applied Forestry 20:205-215.

Losensky, B.J. 1994. Historical vegetation types of the Interior Columbia River Basin. Report to US Forest Service Intermountain Research Station.

Monserud, R. 1984. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat type. For. Sci. 30:943-965.

Moore, R., D. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. J. Am. Wat. Res. Assoc.

Pfister, R. D., B. L. Kovalchik, S. F. Arno and R. C. Presby. 1977. Forest habitat-types of Montana. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. GTR-INT-34. 174 p.

Powell, D. 1999. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington: An implementation guide for the Umatilla National Forest. Technical Publication F14-SO-TP-03-99

Reineke, L. H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research 46(7):627-638.

Shumar, M. and J. de Varona. 2009. The potential natural vegetation (PNV) temperature total maximum daily load (TMDL) procedures manual. Idaho Department of Environmental Quality, Boise, ID. 308pp.

Steele, R., R. D. Pfister, R. A. Ryker and J. A. Kittams. 1981. Forest habitat types of central Idaho. USDA Forest Service General Technical Report INT-114.

Sterba, H. and R. Monserud. 1993. The maximum density concept applied to uneven-aged, mixed species stands. For. Sci. 39(3):432-452.

Teply M, McGreer D, Schult D, Seymour P. 2007. Simulating the effects of forest management on large woody debris in streams in northern Idaho. Western Journal of Applied Forestry 22:81-87.

Teply M. and D. McGreer. 2011. Simulating the effects of forest management on stream shade in streams in central Idaho. In preparation.

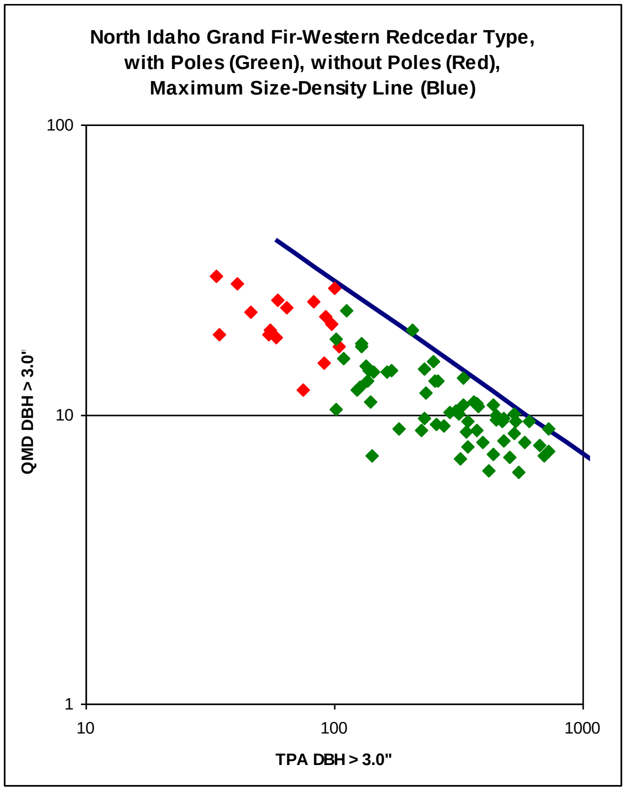
Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model, instream flow information paper 16 U.S. Fish and Wildlife Service, FWS/OBS-84/15.

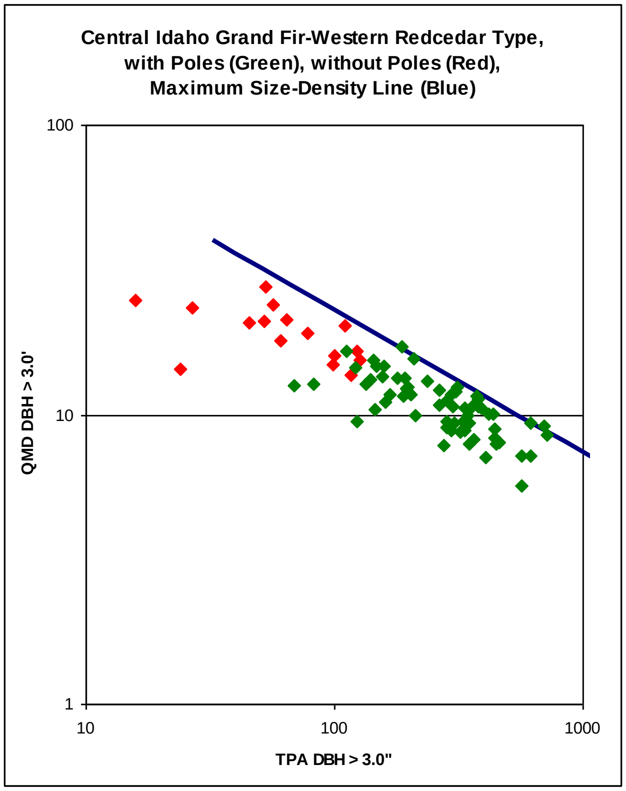
US EPA. 2001. Technical synthesis: Scientific issues relating to temperature criteria for salmon, trout, and char native to the Pacific Northwest. US EPA Report 910-R-01-007.

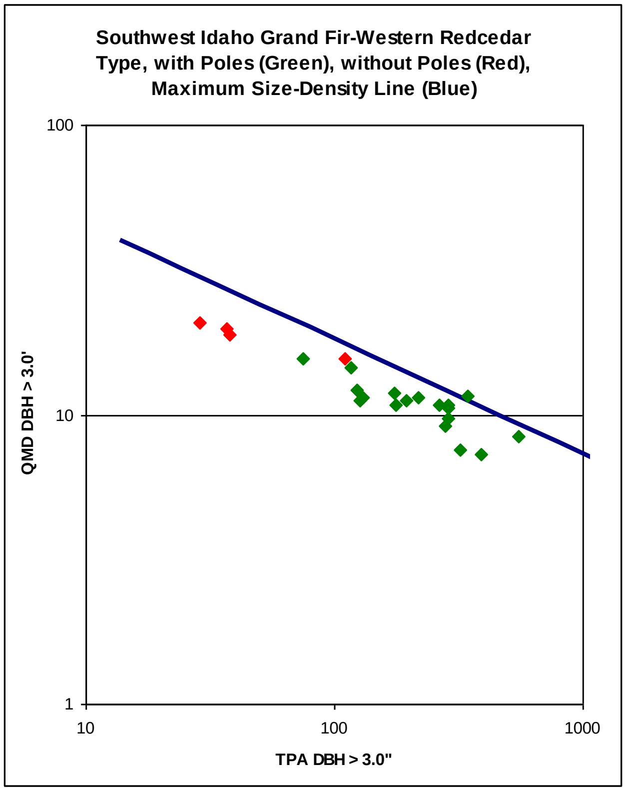
Welty, J.J., T. Beechie, K. Sullivan, D.M. Hyink, R.E. Bilby, C. Andrus, and G. Pess. 2002. Riparian aquatic interaction simulator (RAIS): A model of riparian forest dynamics for the generation of large woody debris and shade. For. Ecol. Manage. 162:299 –318.

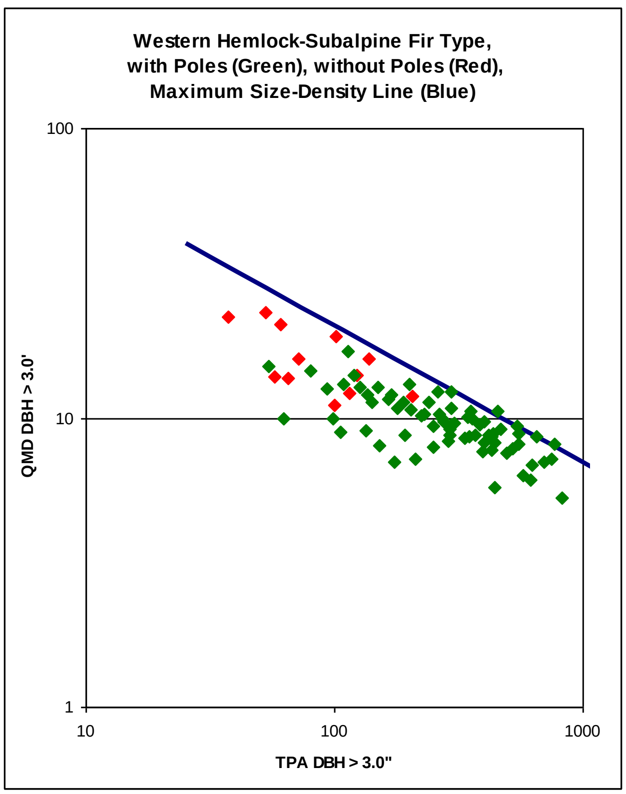
Wykoff, William R.; Crookston, Nicholas L.; Stage, Albert R. User’s guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 112 p.

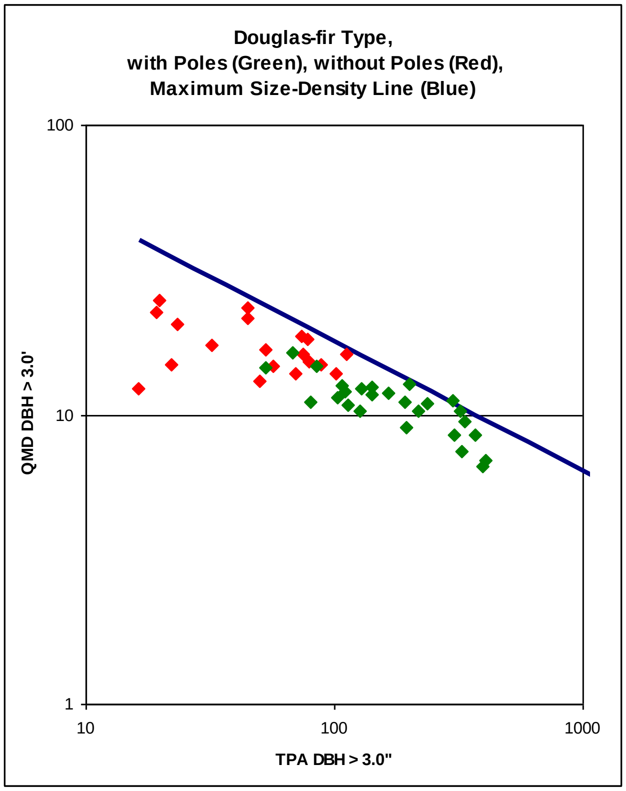
# Appendix A. Maximum Size-Density Relationships by Forest Type


North Idaho Grand Fir-Western Redcedar Type,
with Poles (Green), without Poles (Red),
Maximum Size-Density Line (Blue)
100
10
1
QMD DBH > 3.0"
10
100
1000
TPA DBH > 3.0"


Central Idaho Grand Fir-Western Redcedar Type,
with Poles (Green), without Poles (Red),
Maximum Size-Density Line (Blue)
100
10
1
QMD DBH > 3.0"
10
100
1000
TPA DBH > 3.0"


Southwest Idaho Grand Fir-Western Redcedar Type, with Poles (Green), without Poles (Red), Maximum Size-Density Line (Blue)
100
10
1
10
100
1000
QMD DBH > 3.0"
TPA DBH > 3.0"


Western Hemlock-Subalpine Fir Type, with Poles (Green), without Poles (Red), Maximum Size-Density Line (Blue)
100
10
1
10
100
1000
QMD DBH > 3.0"
TPA DBH > 3.0"

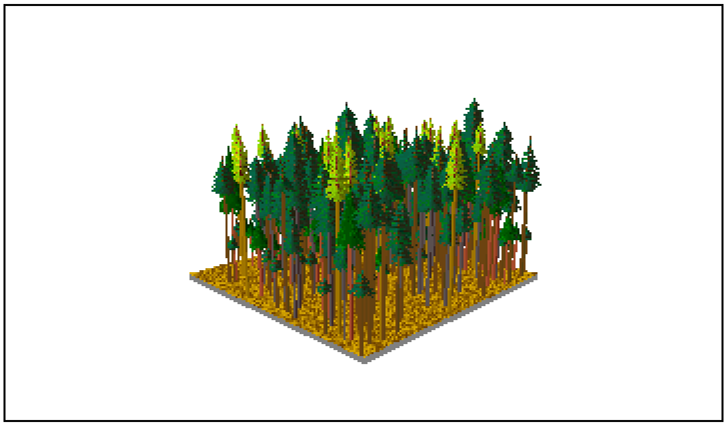


Douglas-fir Type,
with Poles (Green), without Poles (Red),
Maximum Size-Density Line (Blue)
QMD DBH > 3.0"
TPA DBH > 3.0"
100
10
1
10
100
1000

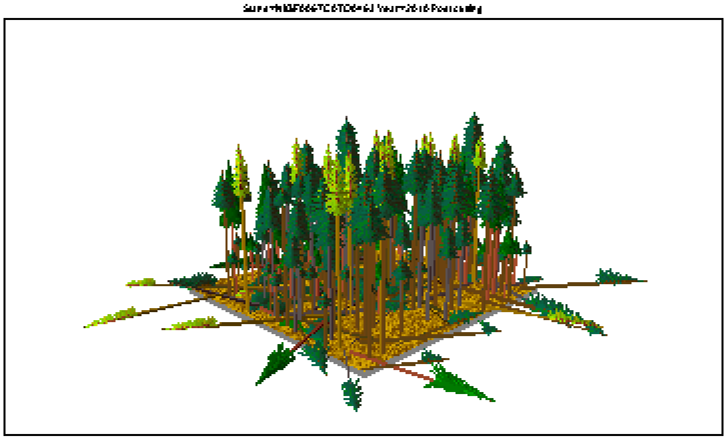
# Appendix B. Examples of Relative Stocking Levels by Forest Type

North Idaho Grand Fir-Western Redcedar Type

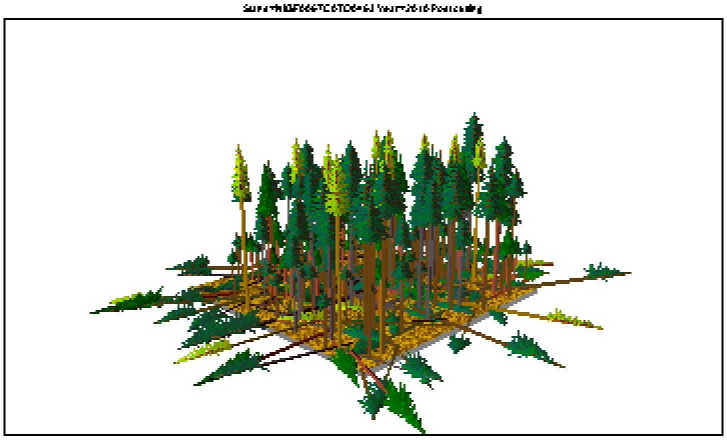
Unharvested, Zone of Competition-induced Mortality



Uniformly Thinned, Target Thinning Levels (40% to 55%)



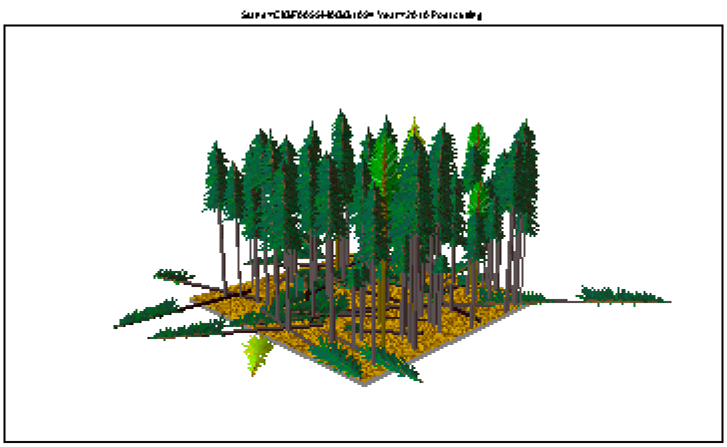
Uniformly Thinned, Lower Limit of Full Site Occupancy



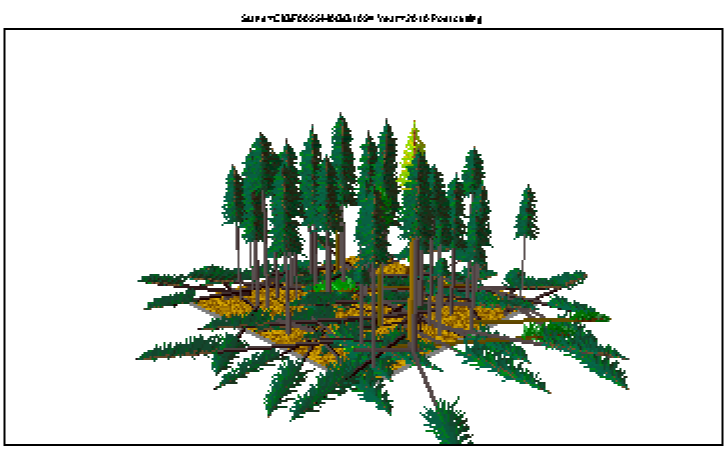
Central Idaho Grand Fir-Western Redcedar Type

Unharvested, Zone of Competition-induced Mortality

Uniformly Thinned, Target Thinning Levels (40% to 55%)

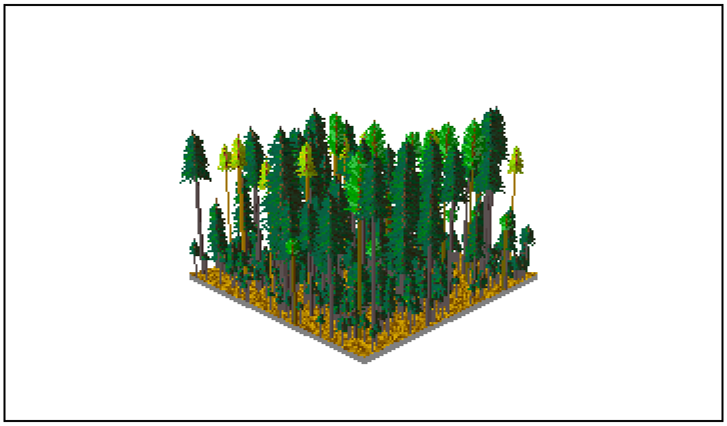


Uniformly Thinned, Lower Limit of Full Site Occupancy

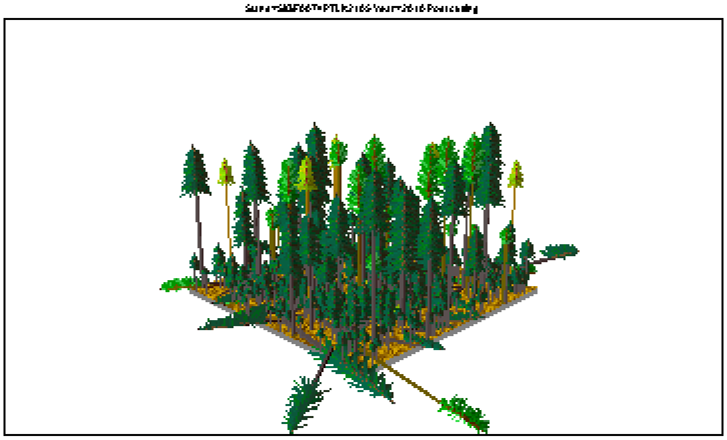


Southwest Idaho Grand Fir-Western Redcedar Type

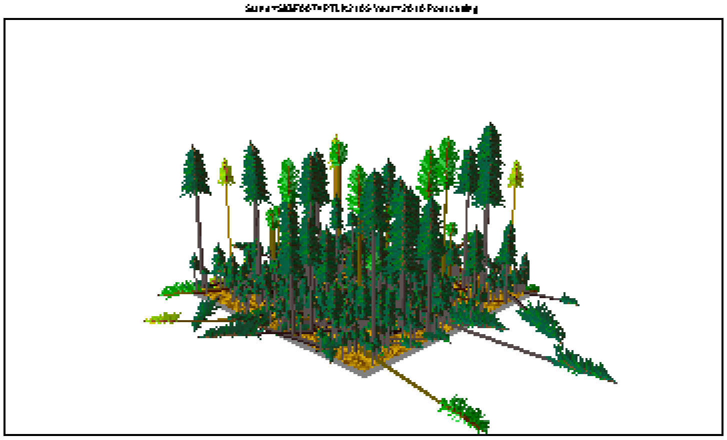
Unharvested, Zone of Competition-induced Mortality



Uniformly Thinned, Target Thinning Levels (40% to 55%)

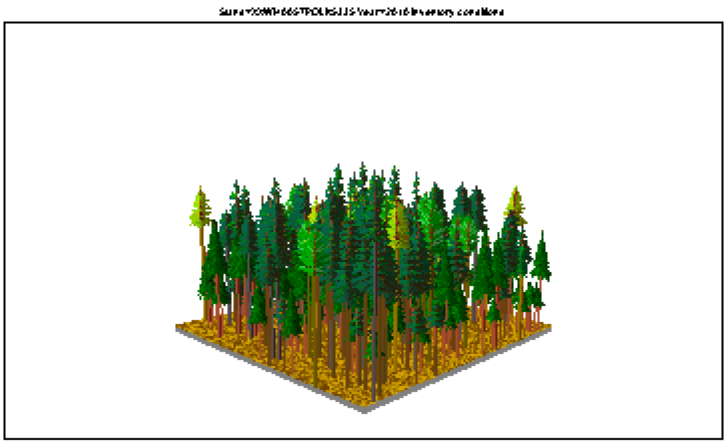


Uniformly Thinned, Lower Limit of Full Site Occupancy

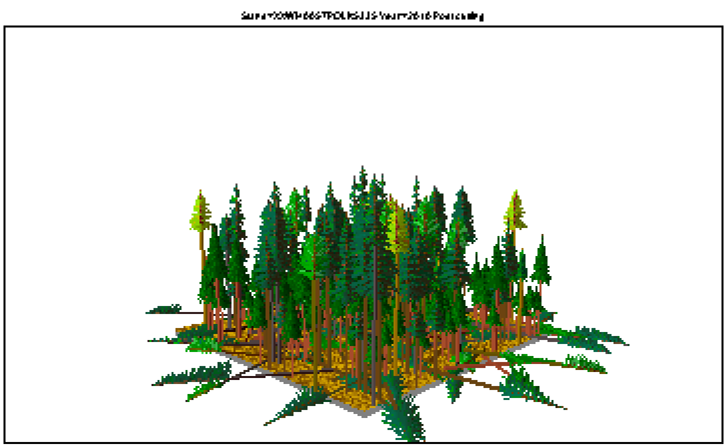


Western Hemlock-Subalpine Fir Type

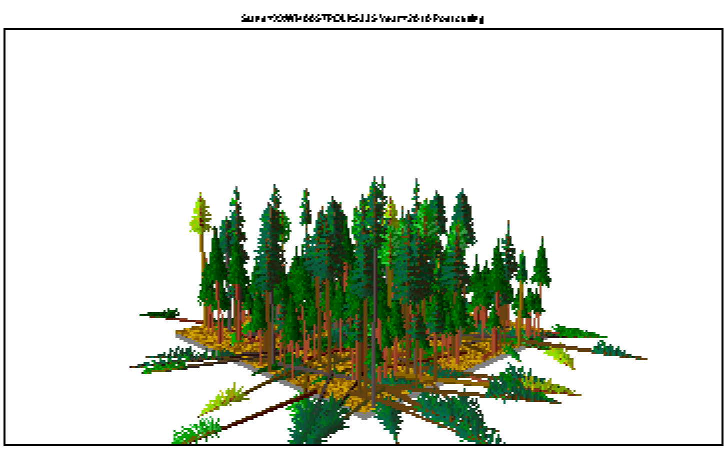
Unharvested, Zone of Competition-induced Mortality



Uniformly Thinned, Target Thinning Levels (40% to 55%)

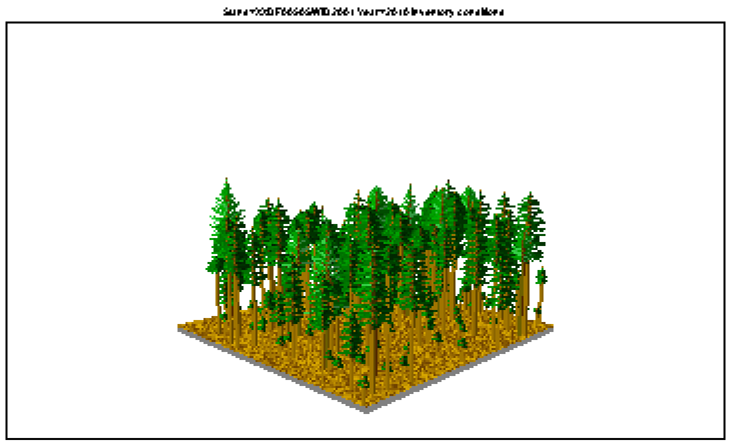


Uniformly Thinned, Lower Limit of Full Site Occupancy

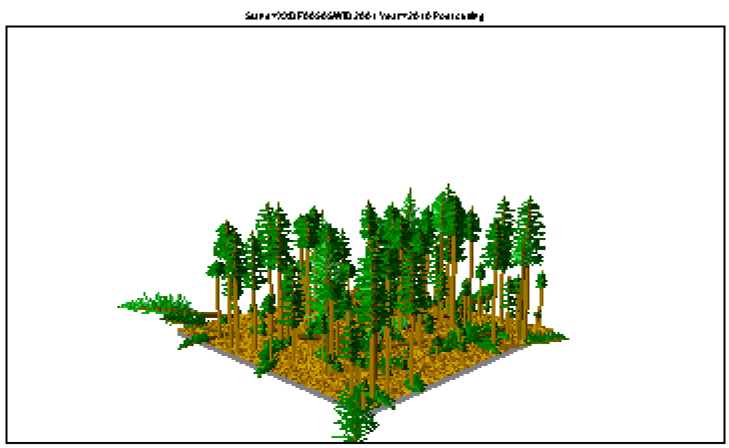


Douglas-fir Type

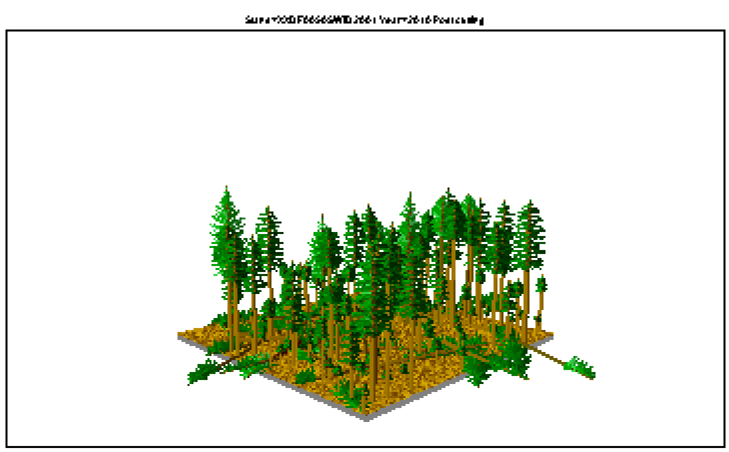
Unharvested, Zone of Competition-induced Mortality



Uniformly Thinned, Target Thinning Levels (40% to 55%)



Uniformly Thinned, Lower Limit of Full Site Occupancy



# Appendix C. Reductions in Volume, LWD, and Shade through Reductions in Riparian Buffer Width and Relative Stocking

Table C-1. Average volume, LWD, and shade provided by unharvested riparian buffers and reductions due to clearing to a residual 75 ft buffer and thinning within the buffer, initial stocking 55% to 70%.

| Forest Type | Metric | Unharvested 100 ft Buffer | | Reduction[1] – Clear to 75 ft Buffer | | Reduction[2] – Thin w/in 75 ft buffer | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| NIGF | Volume[3] | 210,942 | 86,225 | 52,736 | 21,556 | 2,452 | 979 |
| | LWD[4] | 97.5 | 56.7 | 2.4 | 1.5 | 1.4 | 0.7 |
| | Shade 10[5] | 93.9% | 1.7% | 0.5% | 0.5% | 0.5% | 0.4% |
| | Shade 20[6] | 79.0% | 7.0% | 2.3% | 1.0% | 0.7% | 0.2% |
| | Shade 30[7] | 64.8% | 6.9% | 2.6% | 0.6% | 0.6% | 0.1% |
| CIGF | Volume[2] | 149,176 | 34,143 | 37,294 | 8,536 | 1,830 | 464 |
| | LWD[4] | 62.9 | 21.5 | 2.1 | 1.1 | 1.1 | 0.3 |
| | Shade 10[5] | 87.0% | 5.8% | 1.4% | 1.1% | 0.8% | 0.3% |
| | Shade 20[6] | 64.3% | 7.6% | 2.7% | 0.4% | 0.7% | 0.1% |
| | Shade 30[7] | 51.1% | 6.2% | 2.7% | 0.3% | 0.6% | 0.1% |
| SIGF | Volume[2] | 91,142 | 16,052 | 22,785 | 4,013 | 1,113 | 159 |
| | LWD[4] | 48.3 | 14.7 | 0.5 | 0.3 | 0.9 | 0.2 |
| | Shade 10[5] | 72.6% | 6.7% | 2.3% | 0.1% | 0.9% | 0.1% |
| | Shade 20[6] | 50.4% | 5.3% | 2.6% | 0.2% | 0.6% | 0.0% |
| | Shade 30[7] | 39.2% | 4.5% | 2.4% | 0.3% | 0.5% | 0.0% |
| XXWH | Volume[2] | 106,380 | 36,901 | 26,233 | 9,225 | 1,209 | 437 |
| | LWD[4] | 79.3 | 38.7 | 0.3 | 1.5 | 1.1 | 0.3 |
| | Shade 10[5] | 79.5% | 13.9% | 1.3% | 1.0% | 0.7% | 0.3% |
| | Shade 20[6] | 59.6% | 14.5% | 2.3% | 0.5% | 0.6% | 0.1% |
| | Shade 30[7] | 47.1% | 12.4% | 2.3% | 0.4% | 0.5% | 0.1% |
| XXDF | Volume[2] | 88,356 | 25,832 | 22,089 | 6,458 | 1,093 | 274 |
| | LWD[4] | 54.4 | 27.6 | 0.7 | 1.1 | 0.8 | 0.3 |
| | Shade 10[5] | 67.0% | 10.4% | 2.2% | 0.3% | 0.8% | 0.1% |
| | Shade 20[6] | 47.0% | 8.3% | 2.5% | 0.3% | 0.6% | 0.0% |
| | Shade 30[7] | 36.9% | 6.5% | 2.3% | 0.3% | 0.4% | 0.0% |

Notes:

1 – Total reduction in volume, LWD, and shade through removal of the outer 25 ft of vegetation

2 – Percent reduction, per one percent reduction in relative stocking within the residual 75 ft buffer

3 – BF per 1,000 ft of stream; accounting for buffers on both sides of the stream

4 – Net LWD recruitment, # per 1,000 ft of stream; accounting for buffers on both sides of the stream

5 – Effective shade, year 0, along a 10 ft stream; accounting for buffers on both sides of the stream

6 – Effective shade, year 0, along a 20 ft stream; accounting for buffers on both sides of the stream

7 – Effective shade, year 0, along a 30 ft stream; accounting for buffers on both sides of the stream

Table C-2. Average volume, LWD, and shade provided by unharvested riparian buffers and reductions due to clearing to a residual 50 ft buffer and thinning within the buffer, initial stocking 55% to 70%.

| Forest Type | Metric | Unharvested 100 ft Buffer | | Reduction[1] – Clear to 50 ft Buffer | | Reduction[2] – Thin w/in 50 ft buffer | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| NIGF | Volume[3] | 210,942 | 86,225 | 105,471 | 43,112 | 1,635 | 653 |
| | LWD[4] | 97.5 | 56.7 | 13.6 | 4.8 | 1.2 | 0.6 |
| | Shade 10[5] | 93.9% | 1.7% | 1.7% | 1.8% | 0.6% | 0.4% |
| | Shade 20[6] | 79.0% | 7.0% | 6.3% | 2.2% | 0.7% | 0.1% |
| | Shade 30[7] | 64.8% | 6.9% | 7.0% | 1.3% | 0.6% | 0.1% |
| CIGF | Volume[2] | 149,176 | 34,143 | 74,588 | 17,071 | 1,220 | 309 |
| | LWD[4] | 62.9 | 21.5 | 9.4 | 3.2 | 1.0 | 0.3 |
| | Shade 10[5] | 87.0% | 5.8% | 4.4% | 2.6% | 0.8% | 0.2% |
| | Shade 20[6] | 64.3% | 7.6% | 6.9% | 0.8% | 0.7% | 0.1% |
| | Shade 30[7] | 51.1% | 6.2% | 6.5% | 0.6% | 0.5% | 0.1% |
| SIGF | Volume[2] | 91,142 | 16,052 | 45,571 | 8,026 | 742 | 106 |
| | LWD[4] | 48.3 | 14.7 | 5.1 | 1.0 | 0.8 | 0.2 |
| | Shade 10[5] | 72.6% | 6.7% | 5.9% | 0.5% | 0.8% | 0.0% |
| | Shade 20[6] | 50.4% | 5.3% | 6.2% | 0.7% | 0.6% | 0.0% |
| | Shade 30[7] | 39.2% | 4.5% | 5.5% | 0.6% | 0.5% | 0.0% |
| XXWH | Volume[2] | 106,380 | 36,901 | 52,467 | 18,450 | 806 | 291 |
| | LWD[4] | 79.3 | 38.7 | 5.0 | 5.0 | 1.0 | 0.3 |
| | Shade 10[5] | 79.5% | 13.9% | 3.9% | 2.6% | 0.7% | 0.2% |
| | Shade 20[6] | 59.6% | 14.5% | 5.9% | 1.2% | 0.5% | 0.1% |
| | Shade 30[7] | 47.1% | 12.4% | 5.8% | 0.9% | 0.4% | 0.1% |
| XXDF | Volume[2] | 88,356 | 25,832 | 44,178 | 12,916 | 728 | 182 |
| | LWD[4] | 54.4 | 27.6 | 5.4 | 3.3 | 0.7 | 0.2 |
| | Shade 10[5] | 67.0% | 10.4% | 5.7% | 0.7% | 0.8% | 0.1% |
| | Shade 20[6] | 47.0% | 8.3% | 5.9% | 0.9% | 0.5% | 0.0% |
| | Shade 30[7] | 36.9% | 6.5% | 5.3% | 0.8% | 0.4% | 0.0% |

Notes:

1 – Total reduction in volume, LWD, and shade through removal of the outer 50 ft of vegetation

2 – Percent reduction, per one percent reduction in relative stocking within the residual 50 ft buffer

3 – BF per 1,000 ft of stream; accounting for buffers on both sides of the stream

4 – Net LWD recruitment, # per 1,000 ft of stream; accounting for buffers on both sides of the stream

5 – Effective shade, year 0, along a 10 ft stream; accounting for buffers on both sides of the stream

6 – Effective shade, year 0, along a 20 ft stream; accounting for buffers on both sides of the stream

7 – Effective shade, year 0, along a 30 ft stream; accounting for buffers on both sides of the stream

Table C-3. Average volume, LWD, and shade provided by unharvested riparian buffers and reductions due to clearing to a residual 75 ft buffer and thinning within the buffer, initial stocking over 70%.

| | | Unharvested 100 ft Buffer | | Reduction[1] – Clear to 75 ft Buffer | | Reduction[2] – Thin w/in 75 ft buffer | |
|---|---|---|---|---|---|---|---|
| Forest Type | Metric | Mean | SD | Mean | SD | Mean | SD |
| NIGF | Volume[3] | 272,668 | 125,259 | 68,167 | 31,315 | 2,451 | 1,139 |
| | LWD[4] | 138.6 | 86.9 | 3.7 | 3.3 | 1.7 | 0.8 |
| | Shade 10[5] | 95.3% | 1.9% | 0.4% | 0.4% | 0.4% | 0.3% |
| | Shade 20[6] | 83.6% | 9.0% | 1.7% | 1.4% | 0.6% | 0.2% |
| | Shade 30[7] | 70.7% | 10.2% | 2.4% | 1.0% | 0.5% | 0.1% |
| CIGF | Volume[2] | 207,475 | 60,663 | 51,869 | 15,166 | 1,918 | 600 |
| | LWD[4] | 117.8 | 34.9 | 3.6 | 1.9 | 1.4 | 0.5 |
| | Shade 10[5] | 93.3% | 2.1% | 0.5% | 0.6% | 0.5% | 0.2% |
| | Shade 20[6] | 77.3% | 7.3% | 2.6% | 0.9% | 0.6% | 0.2% |
| | Shade 30[7] | 62.8% | 6.9% | 2.8% | 0.6% | 0.5% | 0.1% |
| SIGF | Volume[2] | 140,211 | 39,990 | 35,053 | 9,998 | 1,298 | 332 |
| | LWD[4] | 88.3 | 27.3 | 1.6 | 2.1 | 1.1 | 0.2 |
| | Shade 10[5] | 88.7% | 4.6% | 0.8% | 0.5% | 0.6% | 0.2% |
| | Shade 20[6] | 67.6% | 8.9% | 2.5% | 0.2% | 0.5% | 0.1% |
| | Shade 30[7] | 53.1% | 8.5% | 2.5% | 0.3% | 0.4% | 0.1% |
| XXWH | Volume[2] | 168,804 | 47,482 | 42,288 | 11,871 | 1,554 | 416 |
| | LWD[4] | 121.6 | 43.5 | 2.2 | 1.9 | 1.3 | 0.4 |
| | Shade 10[5] | 91.1% | 10.9% | 0.5% | 0.6% | 0.4% | 0.2% |
| | Shade 20[6] | 77.6% | 13.3% | 1.9% | 0.9% | 0.5% | 0.1% |
| | Shade 30[7] | 63.6% | 11.8% | 2.3% | 0.6% | 0.5% | 0.1% |
| XXDF | Volume[2] | 127,921 | 15,784 | 31,980 | 3,946 | 1,228 | 295 |
| | LWD[4] | 65.2 | 30.5 | 1.0 | 0.7 | 0.8 | 0.3 |
| | Shade 10[5] | 75.0% | 12.0% | 2.1% | 0.3% | 0.7% | 0.1% |
| | Shade 20[6] | 53.0% | 9.5% | 2.7% | 0.3% | 0.5% | 0.0% |
| | Shade 30[7] | 41.7% | 7.7% | 2.5% | 0.3% | 0.4% | 0.0% |

Notes:

1 – Total reduction in volume, LWD, and shade through removal of the outer 25 ft of vegetation

2 – Percent reduction, per one percent reduction in relative stocking within the residual 75 ft buffer

3 – BF per 1,000 ft of stream; accounting for buffers on both sides of the stream

4 – Net LWD recruitment, # per 1,000 ft of stream; accounting for buffers on both sides of the stream

5 – Effective shade, year 0, along a 10 ft stream; accounting for buffers on both sides of the stream

6 – Effective shade, year 0, along a 20 ft stream; accounting for buffers on both sides of the stream

7 – Effective shade, year 0, along a 30 ft stream; accounting for buffers on both sides of the stream

Table C-4. Average volume, LWD, and shade provided by unharvested riparian buffers and reductions due to clearing to a residual 50 ft buffer and thinning within the buffer, initial stocking over 70%.

| Forest Type | Metric | Unharvested 100 ft Buffer | | Reduction[1] – Clear to 50 ft Buffer | | Reduction[2] – Thin w/in 50 ft buffer | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| NIGF | Volume[3] | 272,668 | 125,259 | 136,334 | 62,630 | 1,634 | 759 |
| | LWD[4] | 138.6 | 86.9 | 20.0 | 10.1 | 1.4 | 0.7 |
| | Shade 10[5] | 95.3% | 1.9% | 1.7% | 1.8% | 0.5% | 0.3% |
| | Shade 20[6] | 83.6% | 9.0% | 5.0% | 3.0% | 0.6% | 0.2% |
| | Shade 30[7] | 70.7% | 10.2% | 6.5% | 2.2% | 0.5% | 0.1% |
| CIGF | Volume[2] | 207,475 | 60,663 | 103,738 | 30,331 | 1,278 | 400 |
| | LWD[4] | 117.8 | 34.9 | 18.1 | 5.2 | 1.2 | 0.4 |
| | Shade 10[5] | 93.3% | 2.1% | 1.7% | 1.8% | 0.6% | 0.2% |
| | Shade 20[6] | 77.3% | 7.3% | 6.9% | 2.2% | 0.6% | 0.1% |
| | Shade 30[7] | 62.8% | 6.9% | 7.1% | 1.4% | 0.5% | 0.1% |
| SIGF | Volume[2] | 140,211 | 39,990 | 70,106 | 19,995 | 865 | 221 |
| | LWD[4] | 88.3 | 27.3 | 10.0 | 3.2 | 1.0 | 0.2 |
| | Shade 10[5] | 88.7% | 4.6% | 2.7% | 2.2% | 0.6% | 0.2% |
| | Shade 20[6] | 67.6% | 8.9% | 6.6% | 0.6% | 0.5% | 0.1% |
| | Shade 30[7] | 53.1% | 8.5% | 6.4% | 0.8% | 0.4% | 0.1% |
| XXWH | Volume[2] | 168,804 | 47,482 | 84,576 | 23,741 | 1,036 | 277 |
| | LWD[4] | 121.6 | 43.5 | 16.1 | 9.2 | 1.2 | 0.3 |
| | Shade 10[5] | 91.1% | 10.9% | 1.4% | 1.5% | 0.5% | 0.2% |
| | Shade 20[6] | 77.6% | 13.3% | 5.5% | 2.2% | 0.5% | 0.1% |
| | Shade 30[7] | 63.6% | 11.8% | 6.3% | 1.3% | 0.4% | 0.1% |
| XXDF | Volume[2] | 127,921 | 15,784 | 63,961 | 7,892 | 819 | 197 |
| | LWD[4] | 65.2 | 30.5 | 7.6 | 1.8 | 0.7 | 0.3 |
| | Shade 10[5] | 75.0% | 12.0% | 6.1% | 0.4% | 0.7% | 0.1% |
| | Shade 20[6] | 53.0% | 9.5% | 6.6% | 0.9% | 0.5% | 0.0% |
| | Shade 30[7] | 41.7% | 7.7% | 5.9% | 0.9% | 0.4% | 0.0% |

Notes:

1 – Total reduction in volume, LWD, and shade through removal of the outer 50 ft of vegetation

2 – Percent reduction, per one percent reduction in relative stocking within the residual 50 ft buffer

3 – BF per 1,000 ft of stream; accounting for buffers on both sides of the stream

4 – Net LWD recruitment, # per 1,000 ft of stream; accounting for buffers on both sides of the stream

5 – Effective shade, year 0, along a 10 ft stream; accounting for buffers on both sides of the stream

6 – Effective shade, year 0, along a 20 ft stream; accounting for buffers on both sides of the stream

7 – Effective shade, year 0, along a 30 ft stream; accounting for buffers on both sides of the stream

# Appendix D. Relative Stocking Reduction, Shade Loss and Shade Recovery at Increasing Thinning Intensities

Table D-1. Average relative stocking reduction, shade loss and shade recovery at years 10 and 30 using a 50 ft riparian buffer by forest type, stream width, residual stocking level, and relative stocking trend, initial stocking 50% to 70%.

| Forest Type | Stream Width | Residual Stocking | Relative Stocking Trend – Upward[1] | | | | Relative Stocking Trend – Downward[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] |
| NIGF | 10 ft | 35-45 | 27.8 | 8.0% | 95.1% | 96.3% | 23.7 | 23.3% | 78.8% | 83.1% |
| | | 45-55 | 16.0 | 4.6% | 96.7% | 97.2% | 13.7 | 11.4% | 88.1% | 89.0% |
| | | 55-65 | 5.9 | 2.0% | 98.2% | 98.1% | 6.1 | 7.5% | 92.5% | 91.7% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 27.8 | 21.7% | 79.9% | 83.7% | 23.7 | 27.2% | 68.5% | 74.1% |
| | | 45-55 | 16.0 | 14.5% | 85.4% | 86.7% | 13.7 | 19.9% | 75.4% | 78.7% |
| | | 55-65 | 5.9 | 8.0% | 90.5% | 89.6% | 6.1 | 12.5% | 84.7% | 85.0% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 27.8 | 21.3% | 75.8% | 80.7% | 23.7 | 23.3% | 66.3% | 72.2% |
| | | 45-55 | 16.0 | 14.9% | 81.7% | 84.0% | 13.7 | 17.5% | 73.4% | 76.8% |
| | | 55-65 | 5.9 | 9.2% | 87.1% | 86.8% | 6.1 | 11.3% | 82.7% | 83.1% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| CIGF | 10 ft | 35-45 | 19.1 | 20.1% | 82.9% | 87.1% | 18.9 | 20.2% | 80.0% | 83.9% |
| | | 45-55 | 7.7 | 10.0% | 90.2% | 90.5% | 5.9 | 6.8% | 92.5% | 93.0% |
| | | 55-65 | 6.1 | 6.8% | 93.7% | 94.0% | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 19.1 | 19.8% | 75.2% | 79.8% | 18.9 | 18.8% | 73.6% | 78.5% |
| | | 45-55 | 7.7 | 12.2% | 83.4% | 84.5% | 5.9 | 10.0% | 85.5% | 87.1% |
| | | 55-65 | 6.1 | 10.3% | 86.1% | 86.5% | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 19.1 | 17.0% | 73.1% | 77.7% | 18.9 | 16.0% | 71.6% | 76.7% |
| | | 45-55 | 7.7 | 10.8% | 81.5% | 82.7% | 5.9 | 9.0% | 83.4% | 85.4% |
| | | 55-65 | 6.1 | 9.6% | 83.7% | 84.5% | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| SIGF | 10 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 11.2 | 14.7% | 82.2% | 85.4% | -- | -- | -- | -- |
| | | 55-65 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 11.2 | 12.2% | | 81.6% | -- | -- | -- | -- |
| | | 55-65 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 11.2 | 10.3% | | 79.8% | -- | -- | -- | -- |
| | | 55-65 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| XXWH | 10 ft | 35-45 | 19.1 | 16.6% | 84.9% | 88.9% | 23.6 | 24.3% | 69.8% | 73.2% |
| | | 45-55 | 15.9 | 11.0% | 88.6% | 90.8% | 20.3 | 20.8% | 75.4% | 80.3% |
| | | 55-65 | 5.6 | 3.5% | 96.9% | 97.1% | 7.0 | 11.1% | 86.2% | 87.7% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 19.1 | 18.9% | 76.3% | 81.3% | 23.6 | 18.9% | 66.2% | 69.7% |
| | | 45-55 | 15.9 | 13.0% | 81.7% | 84.6% | 20.3 | 16.8% | 71.4% | 76.7% |
| | | 55-65 | 5.6 | 7.7% | 90.0% | 89.8% | 7.0 | 9.9% | 82.3% | 83.9% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 19.1 | 16.6% | 73.9% | 79.3% | 23.6 | 15.6% | 64.5% | 68.1% |
| | | 45-55 | 15.9 | 11.8% | 79.3% | 82.6% | 20.3 | 13.7% | 69.2% | 74.9% |
| | | 55-65 | 5.6 | 8.0% | 87.3% | 87.5% | 7.0 | 8.4% | 80.4% | 82.2% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| XXDF | 10 ft | 35-45 | 20.3 | 20.3% | 75.5% | 81.5% | 23.5 | 23.9% | 70.9% | 75.8% |
| | | 45-55 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 55-65 | 5.1 | 9.3% | 87.7% | 89.1% | 6.1 | 9.6% | 87.8% | 88.6% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 20.3 | 15.8% | 71.8% | 77.7% | 23.5 | 18.6% | 67.0% | 72.2% |
| | | 45-55 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 55-65 | 5.1 | 8.3% | 83.9% | 85.3% | 6.1 | 9.0% | 83.6% | 84.7% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 20.3 | 13.0% | 70.2% | 76.1% | 23.5 | 15.4% | 65.3% | 70.4% |
| | | 45-55 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 55-65 | 5.1 | 7.2% | 82.3% | 83.6% | 6.1 | 7.8% | 81.8% | 82.9% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |

Notes: [1] – Relative stocking trend determined in unmanaged stands; [2] – Absolute reduction in shade from pre-harvest levels within a 100 ft riparian buffer; 3 – Ratio of shade provided under management to that provided by an unharvested 100 ft riparian buffer at year 10 or year 30.

Table D-2. Average relative stocking reduction, shade loss and shade recovery at years 10 and 30 using a 50 ft riparian buffer by forest type, stream width, residual stocking level, and relative stocking trend, initial stocking over 70%.

| Forest Type | Stream Width | Residual Stocking | Relative Stocking Trend – Upward[1] | | | | Relative Stocking Trend – Downward[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] |
| NIGF | 10 ft | 35-45 | 40.4 | 7.1% | 95.6% | 97.4% | 45.0 | 25.1% | 76.5% | 78.8% |
| | | 45-55 | 28.7 | 3.1% | 97.7% | 98.2% | 34.0 | 13.1% | 88.0% | 88.0% |
| | | 55-65 | 16.9 | 1.7% | 98.7% | 98.8% | 25.8 | 9.9% | 91.0% | 91.1% |
| | | 65-75 | 5.2 | 0.5% | 99.3% | 99.1% | 17.3 | 8.3% | 91.5% | 91.0% |
| | 20 ft | 35-45 | 40.4 | 19.3% | 82.2% | 85.8% | 45.0 | 35.0% | 61.2% | 66.2% |
| | | 45-55 | 28.7 | 12.3% | 88.9% | 89.8% | 34.0 | 26.1% | 71.7% | 74.2% |
| | | 55-65 | 16.9 | 6.9% | 93.8% | 93.6% | 25.8 | 20.1% | 78.3% | 79.4% |
| | | 65-75 | 5.2 | 2.7% | 96.7% | 95.4% | 17.3 | 15.2% | 82.2% | 82.7% |
| | 30 ft | 35-45 | 40.4 | 22.5% | 74.8% | 79.6% | 45.0 | 32.1% | 58.0% | 63.7% |
| | | 45-55 | 28.7 | 16.1% | 81.8% | 83.9% | 34.0 | 25.5% | 68.1% | 71.6% |
| | | 55-65 | 16.9 | 10.6% | 88.3% | 88.3% | 25.8 | 20.6% | 74.7% | 76.6% |
| | | 65-75 | 5.2 | 5.1% | 92.8% | 90.8% | 17.3 | 15.6% | 79.2% | 80.1% |
| CIGF | 10 ft | 35-45 | 40.8 | 3.4% | 97.8% | 98.5% | 38.0 | 25.5% | 79.1% | 83.0% |
| | | 45-55 | 29.4 | 1.8% | 98.7% | 98.8% | 25.9 | 15.2% | 87.1% | 88.7% |
| | | 55-65 | 24.8 | 2.2% | 98.4% | 98.8% | 22.4 | 11.2% | 90.7% | 90.3% |
| | | 65-75 | 13.5 | 0.9% | 99.2% | 99.0% | 10.5 | 5.2% | 94.6% | 93.6% |
| | 20 ft | 35-45 | 40.8 | 16.5% | 87.1% | 88.1% | 38.0 | 30.6% | 66.9% | 73.2% |
| | | 45-55 | 29.4 | 9.5% | 91.1% | 90.4% | 25.9 | 21.6% | 75.8% | 79.7% |
| | | 55-65 | 24.8 | 9.8% | 91.7% | 91.0% | 22.4 | 21.2% | 77.6% | 80.7% |
| | | 65-75 | 13.5 | 4.7% | 94.9% | 92.5% | 10.5 | 13.2% | 84.5% | 85.6% |
| | 30 ft | 35-45 | 40.8 | 18.8% | 81.3% | 83.8% | 38.0 | 26.3% | 64.4% | 71.2% |
| | | 45-55 | 29.4 | 12.0% | 86.5% | 86.3% | 25.9 | 19.1% | 73.4% | 77.7% |
| | | 55-65 | 24.8 | 13.5% | 86.1% | 86.8% | 22.4 | 18.9% | 75.3% | 78.8% |
| | | 65-75 | 13.5 | 7.4% | 90.6% | 88.6% | 10.5 | 12.3% | 82.2% | 83.7% |
| SIGF | 10 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 34.4 | 20.6% | 82.1% | 88.4% | 27.0 | 18.7% | 82.8% | 87.9% |
| | | 55-65 | -- | -- | -- | -- | 11.0 | 9.8% | 91.3% | 93.2% |
| | | 65-75 | 17.9 | 8.8% | 92.4% | 94.2% | -- | -- | -- | -- |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 34.4 | 23.9% | 71.3% | 77.7% | 27.0 | 18.0% | 75.7% | 81.0% |
| | | 55-65 | -- | -- | -- | -- | 11.0 | 11.2% | 84.9% | 86.4% |
| | | 65-75 | 17.9 | 15.2% | 81.3% | 84.3% | -- | -- | -- | -- |
| | 30 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 34.4 | 20.5% | 69.0% | 75.6% | 27.0 | 15.2% | 72.3% | 78.2% |
| | | 55-65 | -- | -- | -- | -- | 11.0 | 9.9% | 82.0% | 84.1% |
| | | 65-75 | 17.9 | 13.6% | 78.9% | 82.3% | -- | -- | -- | -- |
| XXWH | 10 ft | 35-45 | -- | -- | -- | -- | 31.7 | 23.8% | 69.9% | 74.3% |
| | | 45-55 | 28.3 | 10.8% | 92.5% | 94.9% | 41.0 | 11.0% | 91.4% | 93.6% |
| | | 55-65 | 13.2 | 2.9% | 97.6% | 97.5% | 23.2 | 7.4% | 91.9% | 92.5% |
| | | 65-75 | -- | -- | -- | -- | 6.2 | 9.0% | 88.9% | 89.8% |
| | 20 ft | 35-45 | -- | -- | -- | -- | 31.7 | 18.9% | 66.2% | 70.8% |
| | | 45-55 | 28.3 | 23.1% | 76.8% | 81.2% | 41.0 | 22.9% | 77.9% | 83.8% |
| | | 55-65 | 13.2 | 13.9% | 85.4% | 86.4% | 23.2 | 14.3% | 82.6% | 84.8% |
| | | 65-75 | -- | -- | -- | -- | 6.2 | 9.1% | 85.1% | 86.3% |
| | 30 ft | 35-45 | -- | -- | -- | -- | 31.7 | 15.4% | 64.0% | 68.9% |
| | | 45-55 | 28.3 | 21.3% | 73.7% | 78.9% | 41.0 | 22.4% | 73.8% | 80.6% |
| | | 55-65 | 13.2 | 13.8% | 82.5% | 84.1% | 23.2 | 14.2% | 79.3% | 82.0% |
| | | 65-75 | -- | -- | -- | -- | 6.2 | 7.8% | 82.9% | 84.6% |
| XXDF | 10 ft | 35-45 | -- | -- | -- | -- | 42.9 | 35.2% | 60.8% | 69.3% |
| | | 45-55 | -- | -- | -- | -- | 17.6 | 17.6% | 76.1% | 80.3% |
| | | 55-65 | -- | -- | -- | -- | 26.7 | 23.5% | 76.2% | 80.6% |
| | | 65-75 | -- | -- | -- | -- | 13.6 | 14.6% | 86.0% | 87.7% |
| | 20 ft | 35-45 | -- | -- | -- | -- | 42.9 | 26.8% | 57.4% | 65.8% |
| | | 45-55 | -- | -- | -- | -- | 17.6 | 13.8% | 72.4% | 76.5% |
| | | 55-65 | -- | -- | -- | -- | 26.7 | 19.1% | 72.4% | 77.0% |
| | | 65-75 | -- | -- | -- | -- | 13.6 | 13.2% | 81.8% | 84.1% |
| | 30 ft | 35-45 | -- | -- | -- | -- | 42.9 | 21.9% | 55.5% | 64.3% |
| | | 45-55 | -- | -- | -- | -- | 17.6 | 11.6% | 70.8% | 74.8% |
| | | 55-65 | -- | -- | -- | -- | 26.7 | 15.9% | 70.4% | 75.2% |
| | | 65-75 | -- | -- | -- | -- | 13.6 | 11.4% | 80.1% | 82.4% |

Notes: [1] – Relative stocking trend determined in unmanaged stands; [2] – Absolute reduction in shade from pre-harvest levels within a 100 ft riparian buffer; 3 – Ratio of shade provided under management to that provided by an unharvested 100 ft riparian buffer at year 10 or year 30.

# Appendix E. Landscape-level Shade Simulations

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# MEMORANDUM

TO: Chris Tretter, Idaho Department of Lands

FROM: Mark Teply, Cramer Fish Sciences

DATE: September 26, 2011

SUBJECT: Using the Path Landscape Model to simulate the long-term, landscape-level development of streamside shade along forested streams in central Idaho

This memo reports on our VDDT (now "wrapped" by the Path Landscape Model) modeling to simulate the effects of management on streamside shade at the landscape-level over a long-term timeframe. In it, I provide a review of our Path model setup (via Attachments) our simulation results. We demonstrate that landscape-levels of shade can be increased over the long-term by thinning stands to maintain stand structures capable of producing the highest levels of shade.

For our demonstration, we used an existing VDDT model that we acquired from the USFS PNW Regional Planner for the Colville National Forest (CNF) and applied it to IDL riparian stands in the Clearwater-Salmon basins. The CNF has fully vetted this model and they are using it in their forest planning analysis. To apply it in the Clearwater-Salmon basin, we developed:

- A crosswalk between vegetation types in the CNF and those in the Clearwater-Salmon
- A crosswalk between vegetation states in the CNF and those in the Cleawater-Salmon

We otherwise used all natural succession transition types (e.g., growth, wildfire, disease, …) and probabilities "as-is" in the CNF VDDT model. Overall, this model setup provided a reasonable basis for comparison purposes. Further details about model setup are in Attachment A.

We used the model to evaluate the potential effects of three management regimes on shade:

- "No Harvest"—where we simulated only natural transition types (as in Attachment D). This represents the basis of comparison of our two "management" regimes (next).

- "Indiscriminant Thinning"—where we simulate "No Harvest" transitions but also thin stands across a range of vegetation classes (aged ~60 to <300) (as in Attachment E).

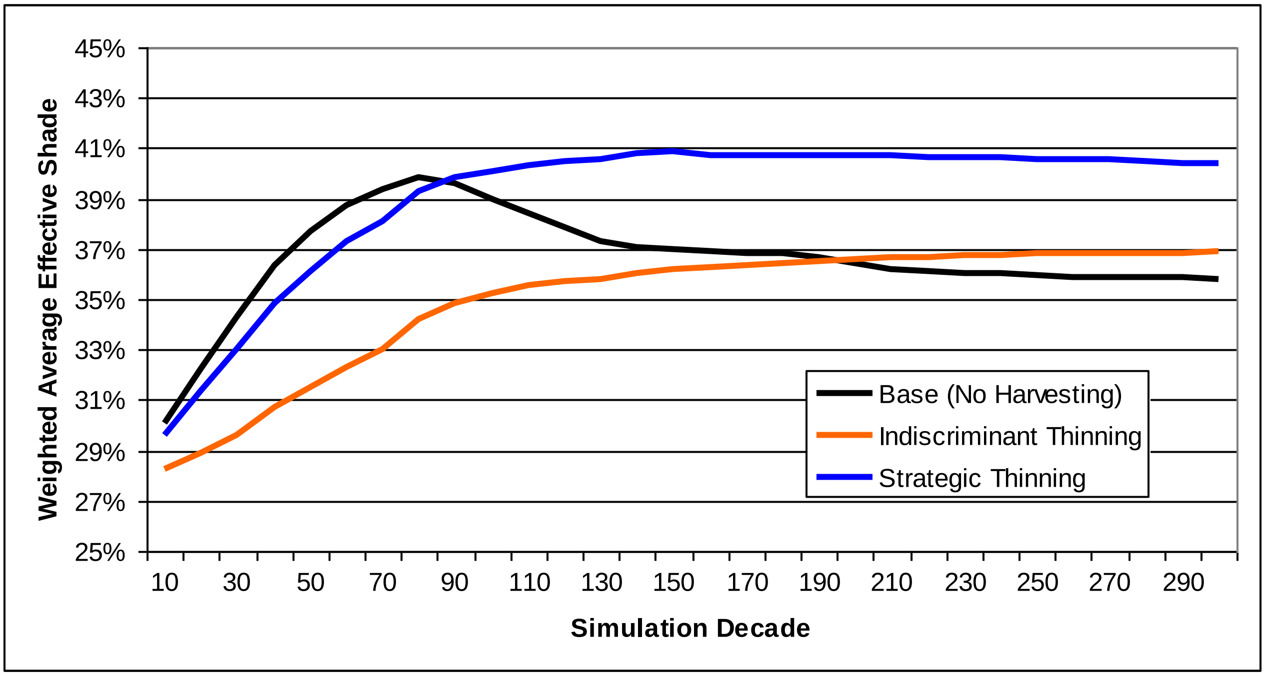
- "Strategic Thinning"— where we simulate "No Harvest" transitions but also thin stands with the highest shade levels within each PVT zone (as in Attachment F).

"Indiscriminant Thinning" was limited to instances where the CNF model had existing natural transitions that approximated a thinning such as that being considered by FPAAC. Some are similar to uniform thinning, others are similar to thinning from above. Prior analyses indicate that, under similar thinning regimes considered by FPAAC, canopy cover typically recovers to pre-harvest levels. However, this sometimes means stand conditions are maintained that provide low levels of shade and delaying development of stand conditions where higher levels of shade could be achieved. When thinning was an option, it had a 1-in-20 chance of occurring within any year.

"Strategic Thinning" was limited to vegetation states that provide the highest levels of shade relative to younger and older stands. We used these thinning activities in order to maintain high levels of shade and to delay natural transition to vegetation states that provide lower levels of shade. Prior analyses indicate that, under thinning regimes considered by FPAAC, canopy cover typically recover to pre-harvest levels. We also have demonstrated that shade levels tend to decrease as stands become older and canopies diversify. When thinning was an option (i.e., when as stand was in a high shade condition), it had a 1-in-20 chance of occurring within any year.

Figure 1 compares the average shade outcome for each simulation by decade. Details of our shade calculations are in Attachment G. Each management regime starts with low levels of shade and, for the first 80 years, all trend upwards. Initial low shade levels reflect initial conditions in the Clearwater-Salmon basin. Most area is in a vegetation state younger than those stand conditions providing the maximum amount of shade (see Attachment A, Table 2). Over time, this wave of young stands grows and transitions to high shade producing stand conditions. The rate of this increase varies by management regime. The differences between "No Harvest" shade levels and "Strategic Thinning" levels are less than 1.5% over this time frame. Shade levels associated with the "Indiscriminant Thinning" are about 1.8% to 6.4% lower than "No Harvest" over this time.

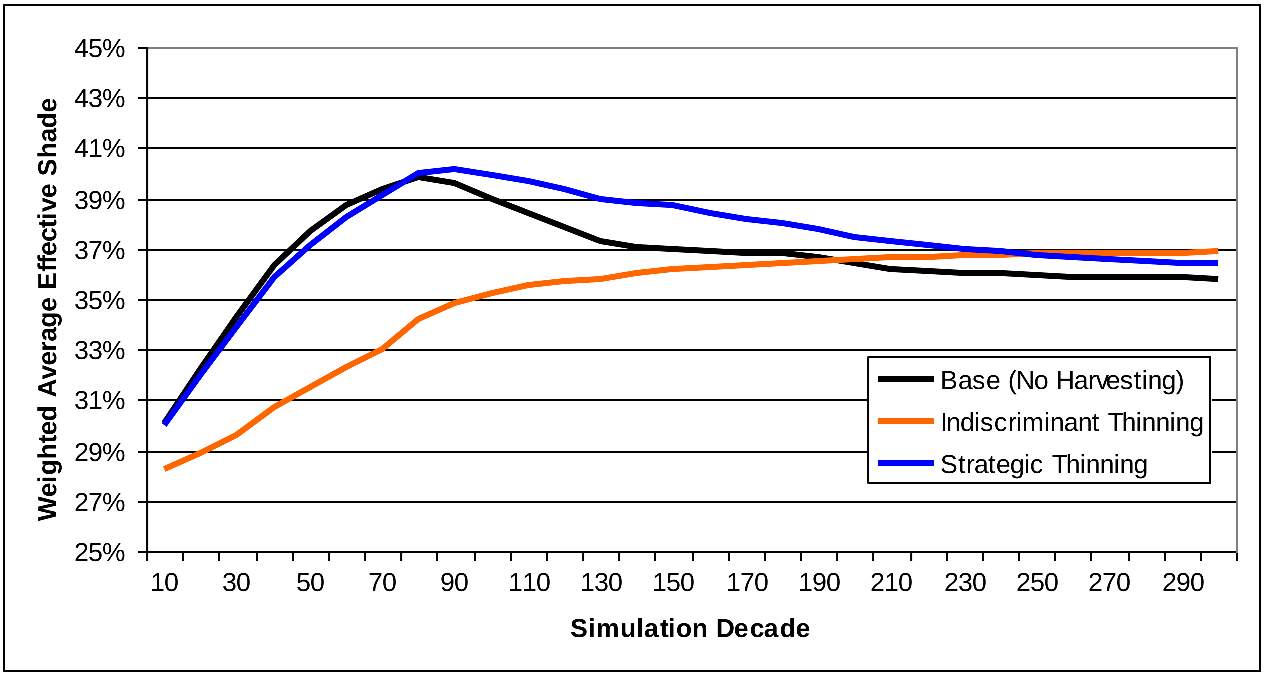
Figure 1. Comparison of simulated effective shade among three management alternatives.




At 80 years, shade levels associated with the "No Harvest" regime peak and then decrease for the remainder of the 300-year simulation period. This reflects the "wave" of younger stands in the Clearwater-Salmon basin achieving stand conditions that provide high levels of shade. But, as these stands continue to develop, they "break-up" for various reasons. They tend to transition to older forest vegetation states which provide lower levels of shade. In comparison, shade levels associated with the "Strategic Thinning" regime continue to rise to about 41% at year 150 and remain more or less constant for the remainder of the 300-year period. This is a direct result of the strategy we employed when selecting stands for thinning. By focusing thinning on stands that are producing high levels of shade, landscape shade is maintained at higher levels (up to about 5% greater) than occurs without active management in the "No Harvest" regime.

Strategic thinning strategies can likely be improved through finer resolution analysis. For instance, we could employ strategic thinning at lower rates (i.e., lower transition probabilities) such that the rate of near-term landscape level shade increase is comparable to that achieve with "No Harvest" (see Figure 2). However, this outcome is achieved at the expense of long-term shade levels. At some point in time, transition to higher thinning levels would be needed to achieve the long-term levels we saw in Figure 1. Such rules cannot be implemented with Path modeling; such analysis would require segmented modeling and possibly optimization-both beyond our scope.

Figure 2. Comparison of simulated effective shade among three management alternatives with Strategic Thinning used at a lower rate (1-in-100 chance) than simulated in Figure 1.




Overall, this demonstration provides a useful proof-of-concept that can be applied to FPAAC rule-making. This analysis demonstrates that strategic thinning can be a useful tool for maintaining and restoring riparian function. The magnitude of effect depends on the mix of stand conditions, but it is positive. When the distribution of stand conditions is skewed towards young stands, modeling indicates that strategic thinning results in increased shade levels and sets-up the landscape for higher long-term shade levels than would have occurred without management. When stand conditions favor high shade levels across the landscape, modeling indicates that strategic thinning can maintain high shade levels, counter to the decreasing trend under passive management.

## ATTACHMENT A

## Path Model Setup

*Initial Conditions*

We conducted our simulations for primary forestlands managed by IDL along Class I streams in the Clearwater-Salmon Basins. This is the same analysis area considered in IFP analyses. For simulation purposes, we assumed a total analysis area of 100,000 ac.

We used three CNF VDDT potential vegetation type (PVT) zones that are analogous to the predominant habitat types encountered in the IDL riparian survey in the Clearwater-Salmon:

- The CNF mixed conifer–cool/moist type (COF_fcm) directly correlates to the drier Douglas-fir and grand fir habitat types found in the Clearwater-Salmon surveys;
- The CNF western redcedar/western hemlock-moist type (COF_frn) *approximates* the western redcedar habitat types encountered in the IDL riparian survey; and,
- The CNF subalpine fir-cool/dry type (COF_fcd) directly correlates to the subalpine fir series found at upper elevations within the Clearwater-Salmon.

We prepared a crosswalk between habitat types (described in Williams et al. 1995) underlying these three PVT zones and those we encountered in the IDL riparian survey in the Clearwater-Salmon basin (described by Cooper et al. 1991) (see Table 1). Many habitat types in the CNF have direct correlates in the Clearwater-Salmon per these references. Most are related.

We then classified plots in the IDL riparian survey according to CNF structural stage definitions (Attachment B) based on tree size, canopy closure, and number of canopies. We were able to use canopy metrics that we derived using the COVER extension to FVS (Crookston and Stage 1991) to classify the IDL riparian survey plots. We calculated these metrics during our 2009/2010 shade analyses using these IDL riparian survey plots. We informed the CNF classifications as follows:

- Size Class – based on the QMD of the upper canopy stratum reported by FVS
- Canopy Closure – based on the total non-overlapping canopy cover reported by FVS
- Number of Canopies – based on the number of canopy strata reported by FVS

Most plots in the IDL riparian survey had stand structures classified according the CNF rules that existed within the CNF VDDT models; however, there were some structures found in the IDL riparian survey that had to be reclassified. A crosswalk between can be found in Attachment C. We made the following judgment calls in our reclassifications:

- Low Density Canopy Closure – Many IDL riparian plots were classified as “low density” canopy covers for which there were no CNF model correlates. Since FVS canopy cover estimates are likely under-predicted in this range (see Teply and McGreer 2011 in prep), we “upgraded” canopy cover in these instances from “low density” to “medium density”.

- Single Storied Stands – Many IDL riparian plots had single story stand structures for which there were no CNF model correlates. This was common for plots in the western redcedar series, especially in larger size classes. Since we have found that these larger size classes typically have understory components, we “upgraded” these to “multistory” canopies.

- Complex Pole Stands – Many pole-size plots in the IDL riparian survey had complex and dense canopies that were not in the CNF model. Again, this was common in the western redcedar series where only one pole-sized structure class existed – Pm1. Aggregation all pole-sized plots into this class did not appear to alter the stand development trajectory.

Table 2 summarizes the allocation of initial starting conditions by model and structural class. Area is allocated more or less evenly among size classes, representative of area regulation. Overall, the effect of this reclassification on allocation among vegetation states is near-term and more or less comparable among alternatives. Over time, we see any alternative reaching an equilibrium that is independent of the starting conditions. That we have a basis for an initial allocation is a matter of convenience, makes the demonstration more “real”, but has little bearing on the comparisons.

*Transition Types*

We used all natural succession transition types and probabilities “as-is” in the CNF VDDT model. This includes canopy growth and disturbance due to wildfire, insects, and disease. We removed all managed transition types from this model and replaced them with transition types and probabilities specific to our demonstration (we describe this in detail below). CNF VDDT Transition types that we removed included planting, pre-commercial thinning, use of prescribed fire, all harvest activity, and conversion to non-forest land uses. Screenshot schematics of the natural transitions we used in our simulations can be found in Attachment D (along with shade estimates described later).

*Resolutions*

We conducted the simulations at a 120 m resolution; this is approximately the size of a base riparian treatment unit (75 ft either side of a 1,000 ft stream). The Path simulator predicts transitions on a yearly basis; however, we captured results on a 10 yr basis over 300 years.

*Literature Cited*

Cooper, Stephen V.; Neiman, Kenneth E.; Roberts, David W. Rev. 1991. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 143 p.

Crookston, N. and A. Stage. 1999. Percent canopy cover and stand structure statistics from the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-24. Ogden, UT: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p.

Williams, Clinton K.; Kelley, Brian F.; Smith, Bradley G.; Lillybridge, Terry R. 1995. Forested plant associations of the Colville National Forest. Gen. Tech. Rep. PNW-GTR-360. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 375 p. In cooperation with: Pacific Northwest Region, Colville National Forest.

Table 1. Crosswalk of CNF VDDT model habitat types to IDL riparian survey habitat types.

| CNF VDDT Model Habitat Types (Williams et al. 1995) | IDL Riparian Survey Habitat Types (Cooper et al. 1991) | | |
|---|---|---|---|
| | Direct Correlates | Related Type | Related Type |
| Douglas fir/big huckleberry-small red huckleberry-dwarf blueberry | 320<br>PSME/CARU<br>0 Plots | 330<br>PSME/CAGE<br>2 Plots | — |
| Douglas fir-wet non-forest | N/A | — | — |
| Grand fir/big huckleberry-dwarf huckleberry/queencup beadlily | 520<br>ABGR/CLUN<br>15 Plots | 510<br>ABGR/XETE<br>5 Plots | — |
| Western hemlock/big huckleberry/queencup beadlily | 570<br>TSHE/CLUN<br>0 Plots | 530<br>THPL/CLUN<br>38 Plots | — |
| Western hemlock/oxalis-swordfern-moist | 565<br>TSHE/GYDR<br>0 Plots | 540<br>THPL/ATFI<br>32 Plots | 550<br>THPL/OPHO<br>15 Plots |
| Western hemlock/fool's huckleberry/bear grass | 570<br>TSHE/CLUN<br>0 Plots | — | — |
| Western hemlock/dry non-forest | N/A | — | — |
| Western hemlock/wet non-forest | N/A | — | — |
| Subalpine fir/Oregon boxwood/pinegrass | ABLA/CARU<br>0 Plots | — | — |
| Subalpine fir/grouse whortleberry | 720<br>ABLA/VAGL<br>1 Plot | — | — |
| Subalpine fir/big huckleberry/twinflower | — | — | — |
| Subalpine fir/Cascades azalea/beargrass | 670<br>ABLA/MEFE<br>9 Plots | 620<br>ABLA/CLUN<br>1 Plot | — |
| Subalpine fir/dogwood bunchberry-horsetail | N/A | — | — |

| | | | |
|---|---|---|---|
| Subalpine fir/dry-nonforest | N/A | — | — |

Table 2. Initial allocation of area (acres) by PVT zone and structural stage; vegetation states providing the highest levels of effective shade are highlighted.

| Structure | COF_fcm | COF_frn | COF_fcd | Total |
|---|---|---|---|---|
| GF | 4,202 | 5,042 | 1,681 | 10,924 |
| Yo | | 2,521 | | 2,521 |
| Pm1 | | 10,924 | 840 | 11,765 |
| Pc1 | 2,521 | | | 2,521 |
| Sm1 | 840 | | 1,681 | 2,521 |
| Sm2 | | 5,882 | 1,681 | 7,563 |
| Sc1 | 1,681 | | | 1,681 |
| Sc2 | | 6,723 | | 6,723 |
| Mm1 | 1,681 | | | 1,681 |
| Mm2 | 840 | 8,403 | 1,681 | 10,924 |
| Mc2 | 2,521 | 1,681 | 840 | 5,042 |
| Lm1 | 840 | | | 840 |
| Lm2 | 1,681 | 10,084 | 840 | 12,605 |
| Lc1 | 1,681 | | | 1,681 |
| Lc2 | 840 | 2,521 | | 3,361 |
| Gm2 | | 14,286 | | 14,286 |
| Gc2 | | 3,361 | | 3,361 |
| Total | 19,328 | 71,429 | 9,244 | 100,000 |

# ATTACHMENT B

## CNF Structural Stage Definitions

**Structure**

Structural stage information is composed of canopy closure, size class, and number of canopy layers. Canopy closures are compressed into three classes (Table 1). Size classes are compressed into five groups based on quadratic mean diameter (QMD) of the overstory trees to approximate the satellite image (GNN) classification (Table 2). The same structure definitions have been used in all forested models in Region 6 and are based on the following GNN attributes: CANCOV, IMAP_QMD, and IMAP_Layer.

*Table 1: Canopy closure classes used to define structural stages.*

| | **>>>> Canopy closure percent >>>>>** | | | |
|---|---|---|---|---|
| Density | < 10 % | 10 to 40 % | 40 to 60 % | > 60 % |
| Density class | Grass/shrub | Low density (open) | Medium density (medium) | High density (closed) |

Where diameter data is available, size is based on the QMD of the largest 20% of the trees, with a minimum of 20 trees. When diameter data is absent, the largest trees that contribute 25% of the total canopy closure are used. Structure is considered multiple storied when any layer below the dominant canopy constitutes 25% of the total canopy closure and has at least 10% absolute canopy closure (Table 3).

*Table 2: Size classes used to define structural stages.*

| **>>>> Average dbh in inches; size class name >>>>** | | | | | | |
|---|---|---|---|---|---|---|
| 0 (nonstocked) | < 5 " dbh | 5 to 10 " | 10 to 15 " | 15 to 20 " | 20 " to 30 | > 30" dbh |
| Grass/Shrub (GS) | Seed/saps (Y) | Poles (P) | Small trees (S) | Med trees (M) | Large trees (L) | Giant trees (G) |

*Table3: Canopy Layers definitions.*

| **>>>> Number of canopy layers >>>>** | | |
|---|---|---|
| Number of Layers | 1 | 1< |
| Layer Class | Open | Multi |

**Cover**

Cover type information was extracted from the FORTYPIV field in the GNN data. In the same folder is a crosswalk linking each VDDT-PVT to GNN-FORTYPIV to VDDT-Cover.

# ATTACHMENT C

## CNF to IDL Structural Stage Crosswalks

CNF mixed conifer–cool/moist type (COF_fcm)

| Model | VDDTStrCls | IDLStrCls |
|---|---|---|
| fcm | GFp | |
| fcm | Sp | |
| fcm | Yop | |
| fcm | P1p | |
| fcm | S1p | |
| fcm | M1p | |
| fcm | L1p | |
| fcm | GF | GF |
| fcm | S | |
| fcm | Yo | |
| fcm | Pm1 | |
| fcm | Sm1 | So1 |
| fcm | Mm1 | Mm1 |
| fcm | Lm1 | Lo1 |
| fcm | Gm1 | |
| fcm | P2p | |
| fcm | S2p | |
| fcm | Pm2 | |
| fcm | Sm2 | |
| fcm | Mm2 | Mm2 |
| fcm | Lm2 | Lo2 |
| fcm | Gm2 | |
| fcm | Ym | |
| fcm | Pc1 | Pc1 |
| fcm | Sc1 | Sc1 |
| fcm | Mc1 | |
| fcm | Lc1 | Lc1 |
| fcm | Gc1 | |
| fcm | Pc2 | |
| fcm | Sc2 | |
| fcm | Mc2 | Mc2 |
| fcm | Lc2 | Lc2 |
| fcm | Gc2 | |

CNF western redcedar/western hemlock-moist type (COF_frn)

| Model | VDDTStrCls | IDLStrCls |
|---|---|---|
| frn | GFp | |
| frn | Yop | |
| frn | M1p | |
| frn | L1p | |
| frn | G1p | |
| frn | GF | GF |
| frn | Yo | Yc2 |
| frn | Yo | Ym1 |
| frn | Yo | Yo1 |
| frn | Pm1 | Pm1 |
| frn | Pm1 | Pc1 |
| frn | Pm1 | Pc2 |
| frn | Pm1 | Pm2 |
| frn | Pm1 | Po1 |
| frn | Sm2 | Sm2 |
| frn | Sm2 | So1 |
| frn | Sm2 | So2 |
| frn | Mm2 | Mm2 |
| frn | Mm2 | Mm1 |
| frn | Mm2 | Mo1 |
| frn | Mm2 | Mo2 |
| frn | Lm2 | Lm2 |
| frn | Lm2 | Lm1 |
| frn | Lm2 | Lo1 |
| frn | Lm2 | Lo2 |
| frn | Gm2 | Gm2 |
| frn | Gm2 | Gm1 |
| frn | Gm2 | Go1 |
| frn | Gm2 | Go2 |
| frn | Sc2 | Sc2 |
| frn | Sc2 | Sc1 |
| frn | Mc2 | Mc2 |
| frn | Lc2 | Lc2 |
| frn | Lc2 | Lc1 |
| frn | Gc2 | Gc2 |

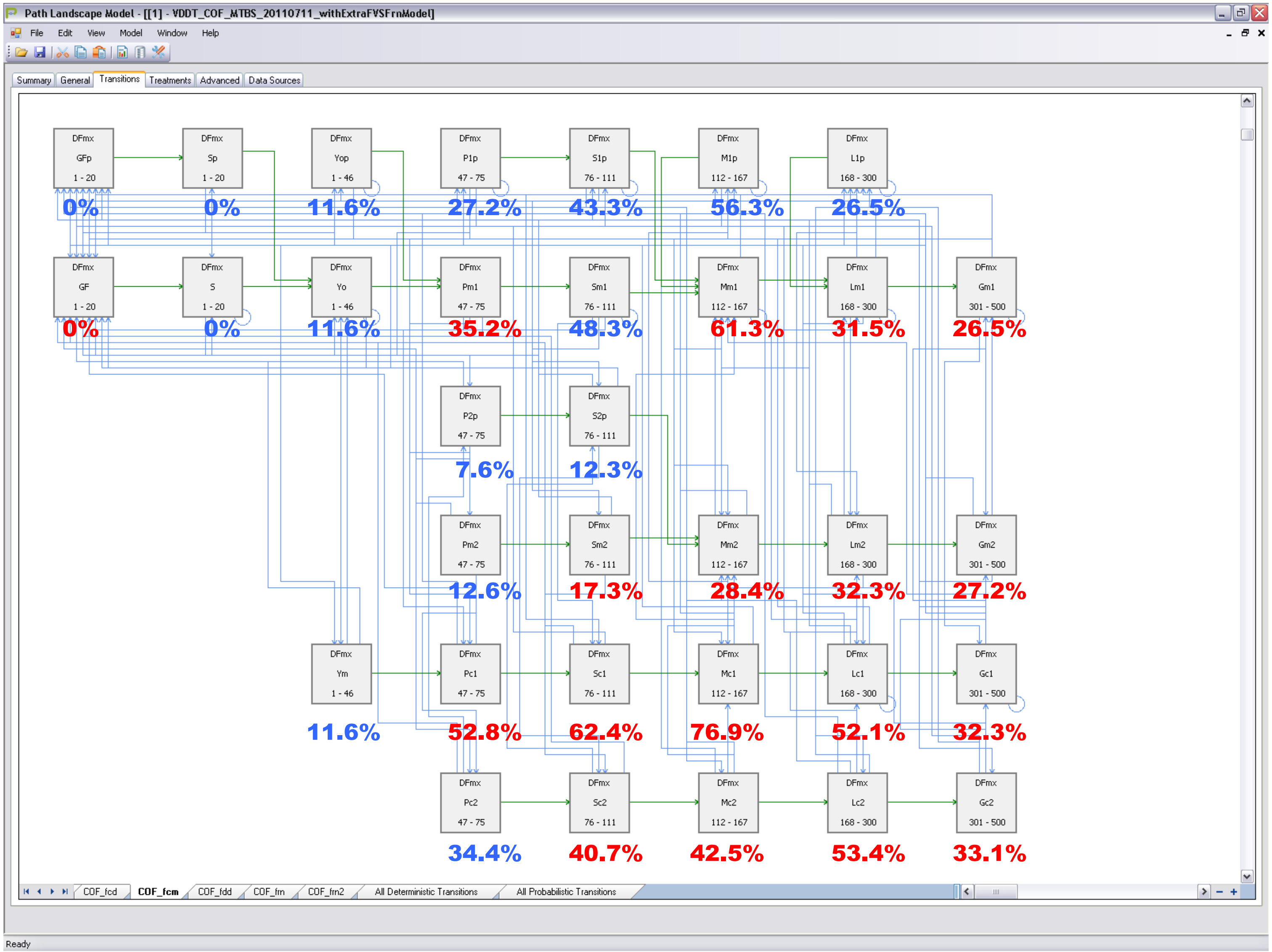
CNF subalpine fir-cool/dry type (COF_fcd)

| Model | VDDTStrCls | IDLStrCls |
|---|---|---|
| fcd | GFp | |
| fcd | Sp | |
| fcd | Yop | |
| fcd | P1p | |
| fcd | S1p | |
| fcd | GF | GF |
| fcd | S | |
| fcd | Yo | |
| fcd | Pm1 | Pm1 |
| fcd | Sm1 | So1 |
| fcd | Mm1 | |
| fcd | Lm1 | |
| fcd | P2p | |
| fcd | S2p | |
| fcd | Pm2 | |
| fcd | Sm2 | So2 |
| fcd | Mm2 | Mo2 |
| fcd | Lm2 | Lo2 |
| fcd | Ym | |
| fcd | Pc1 | |
| fcd | Sc1 | |
| fcd | Mc1 | |
| fcd | Lc1 | |
| fcd | Pc2 | |
| fcd | Sc2 | |
| fcd | Mc2 | Mc2 |
| fcd | Lc2 | |

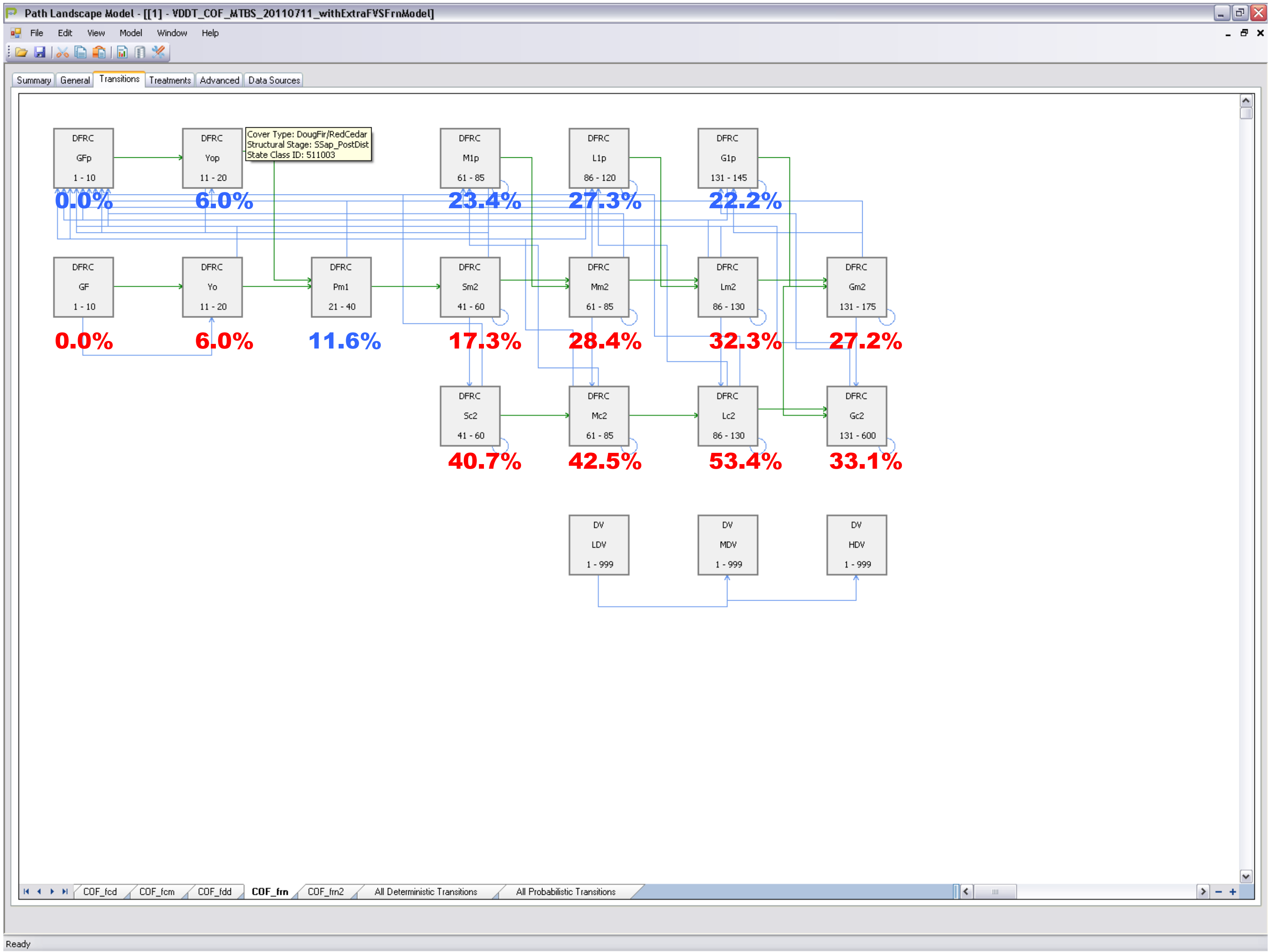
# ATTACHMENT D

## CNF VDDT Model Natural States

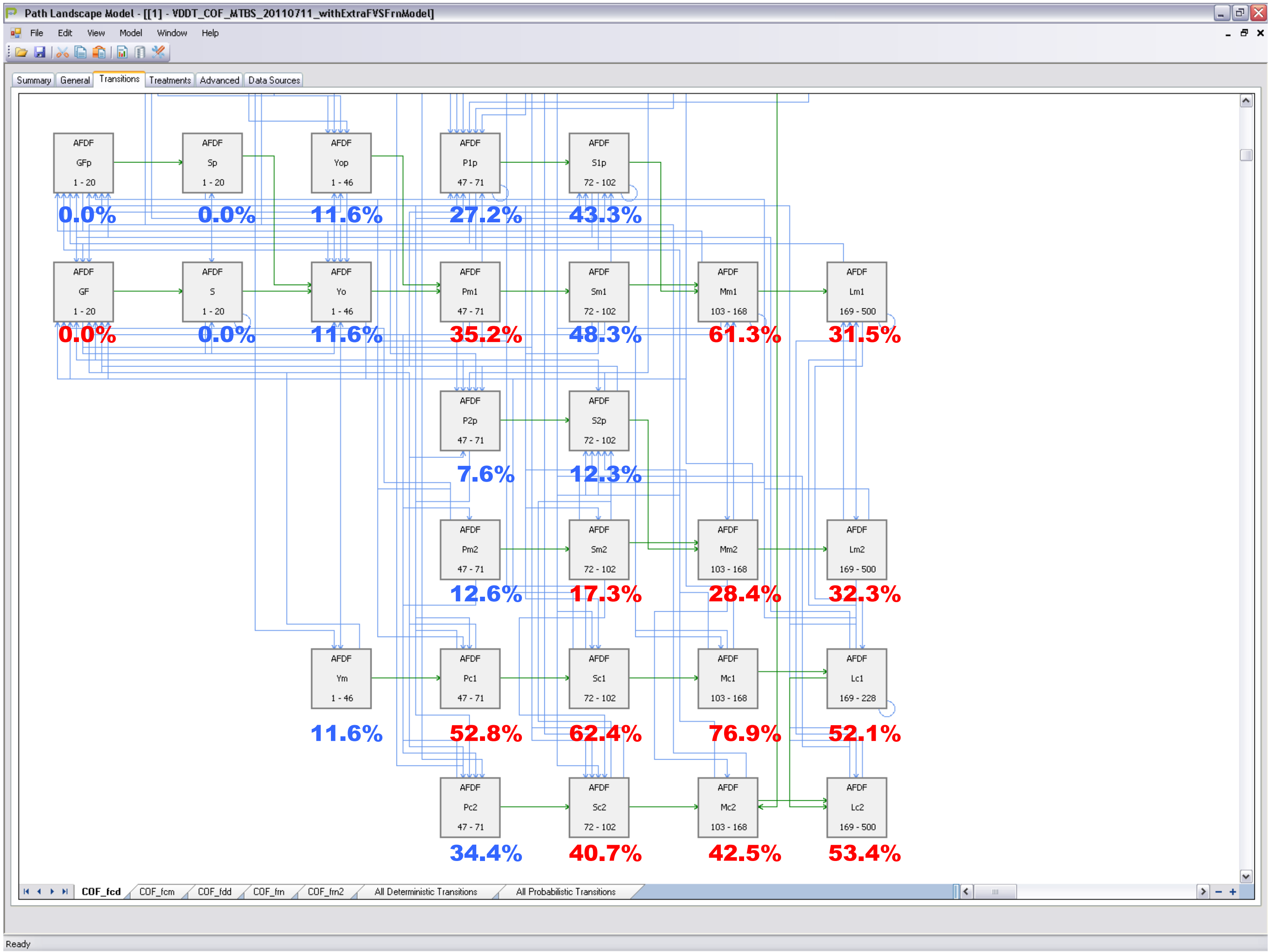
CNF mixed conifer–cool/moist type (COF_fcm)



CNF western redcedar/western hemlock-moist type (COF_frn)



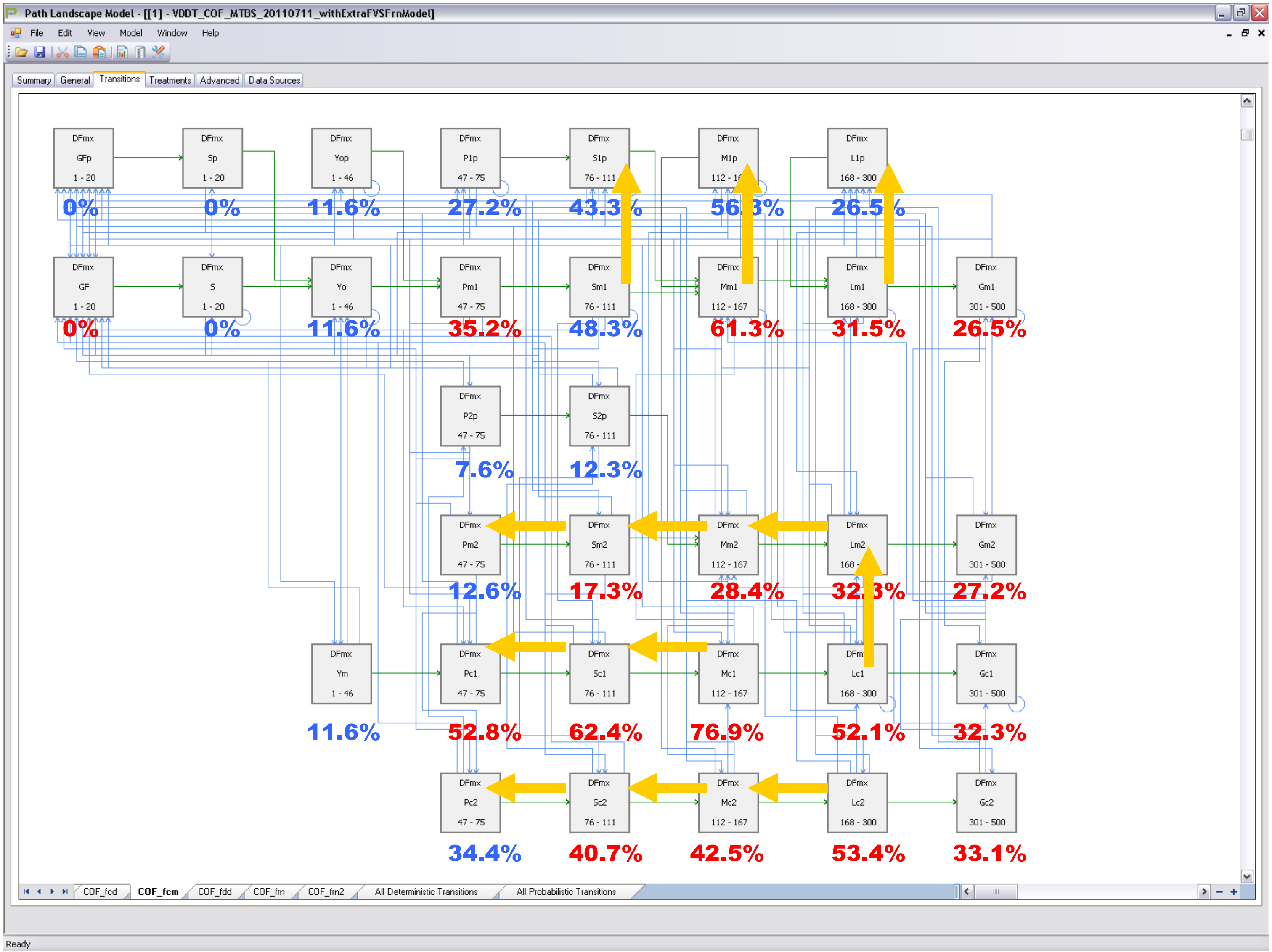
CNF subalpine fir-cool/dry type (COF_fcd)



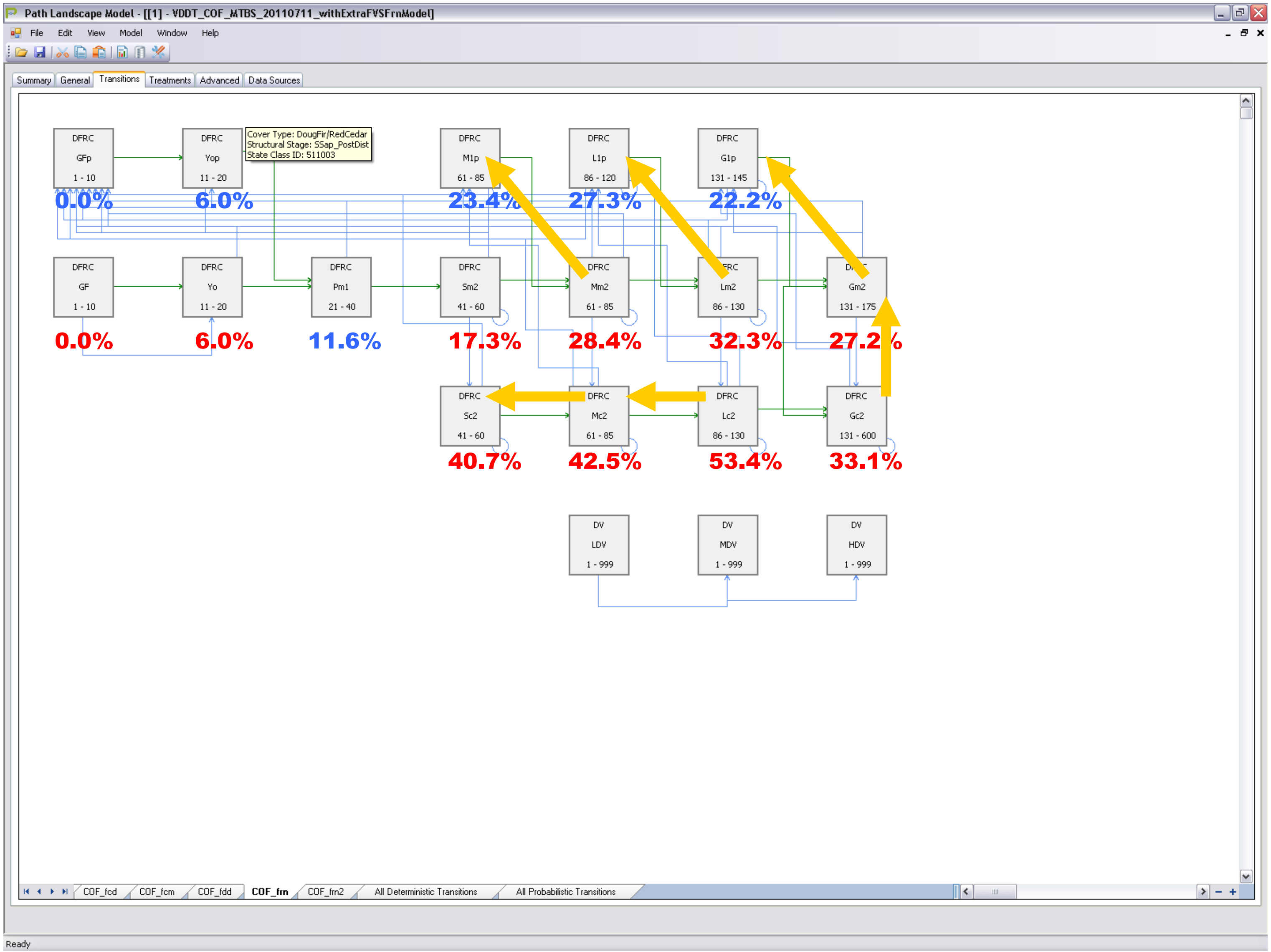
# ATTACHMENT E

## "Indiscriminant Thinning" Transitions (in Gold)

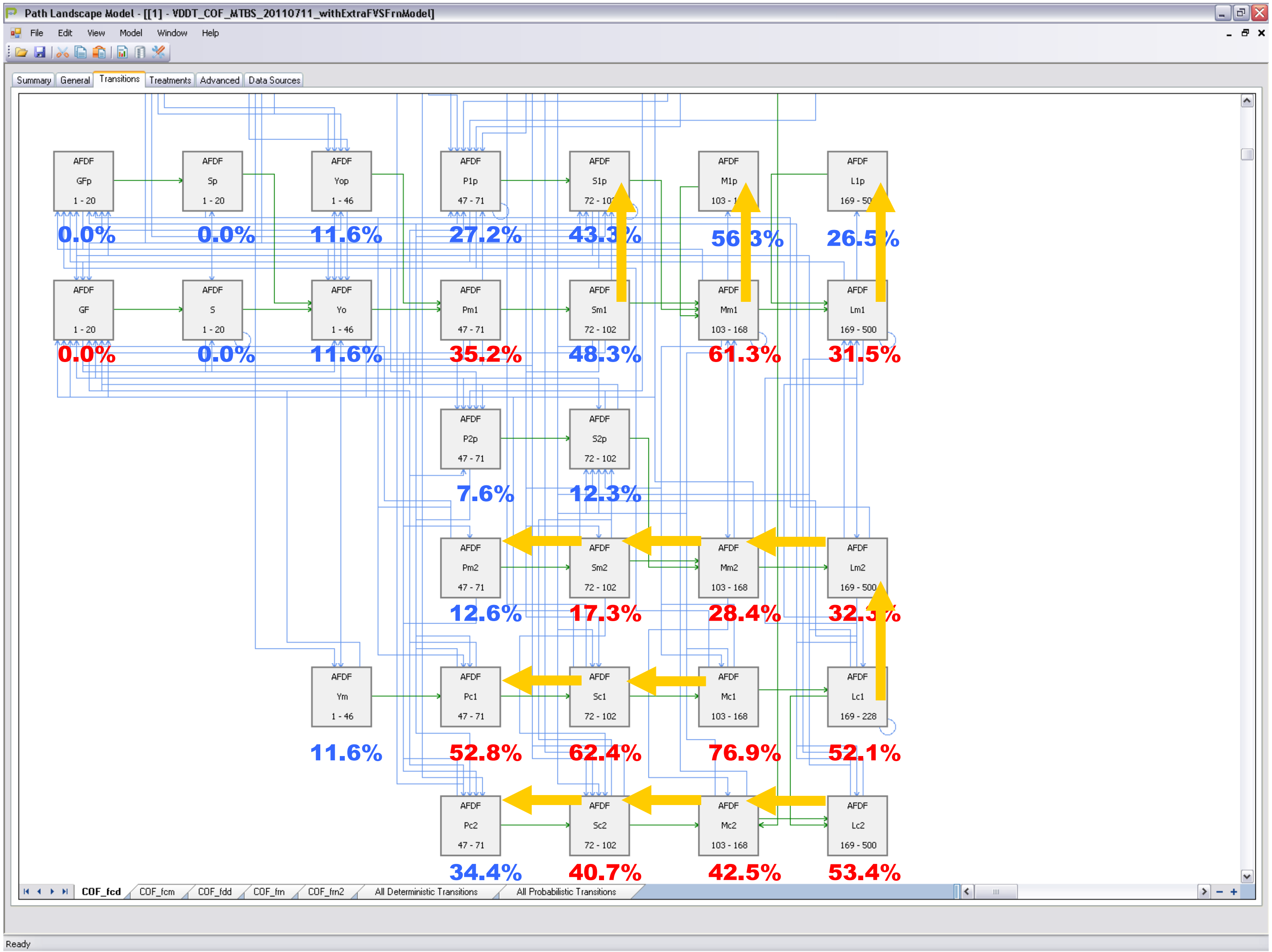
CNF mixed conifer–cool/moist type (COF_fcm)



CNF western redcedar/western hemlock-moist type (COF_frn)



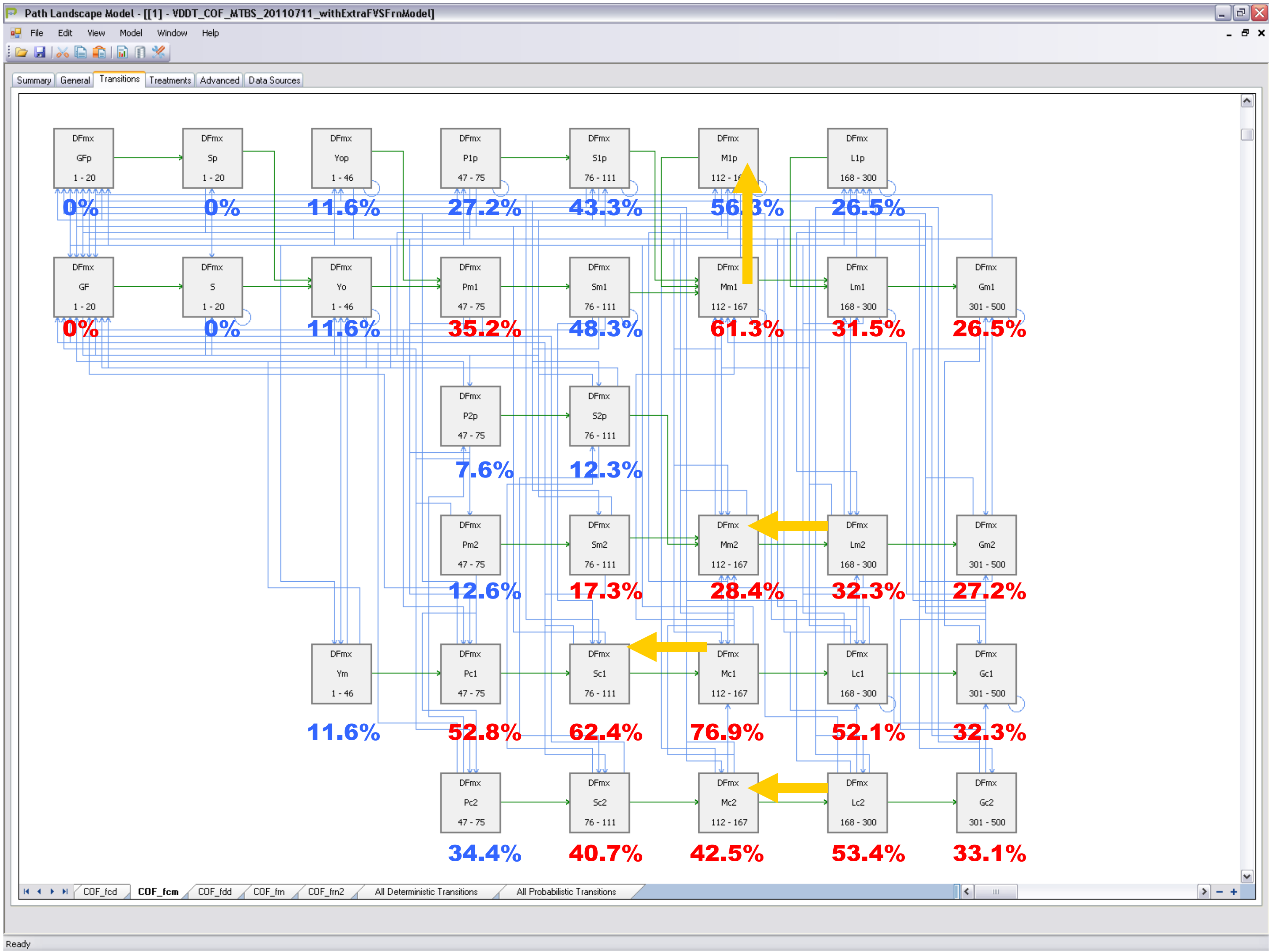
CNF subalpine fir-cool/dry type (COF_fcd)



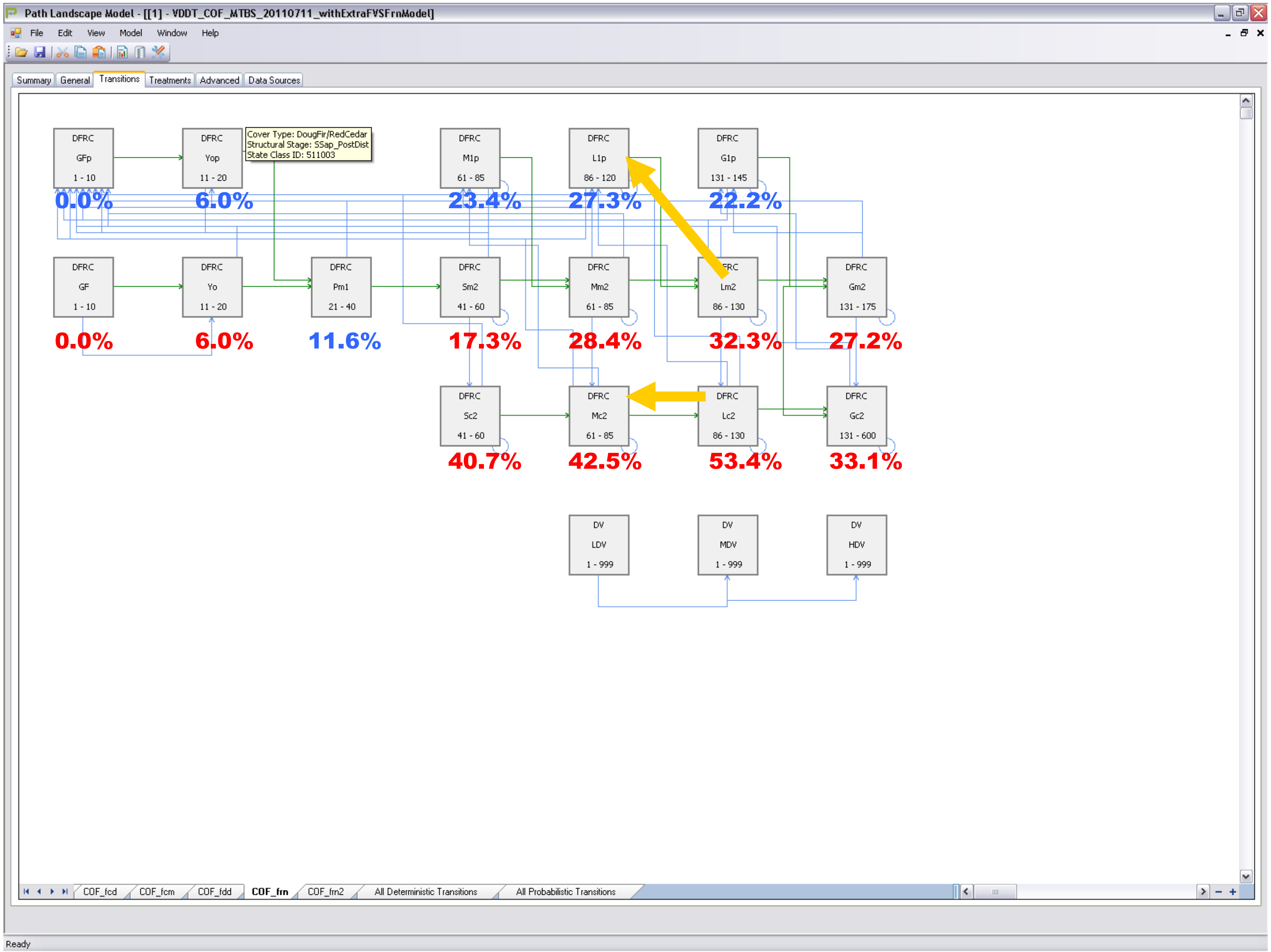
# ATTACHMENT F

## "Strategic Thinning" Transitions (in Gold)

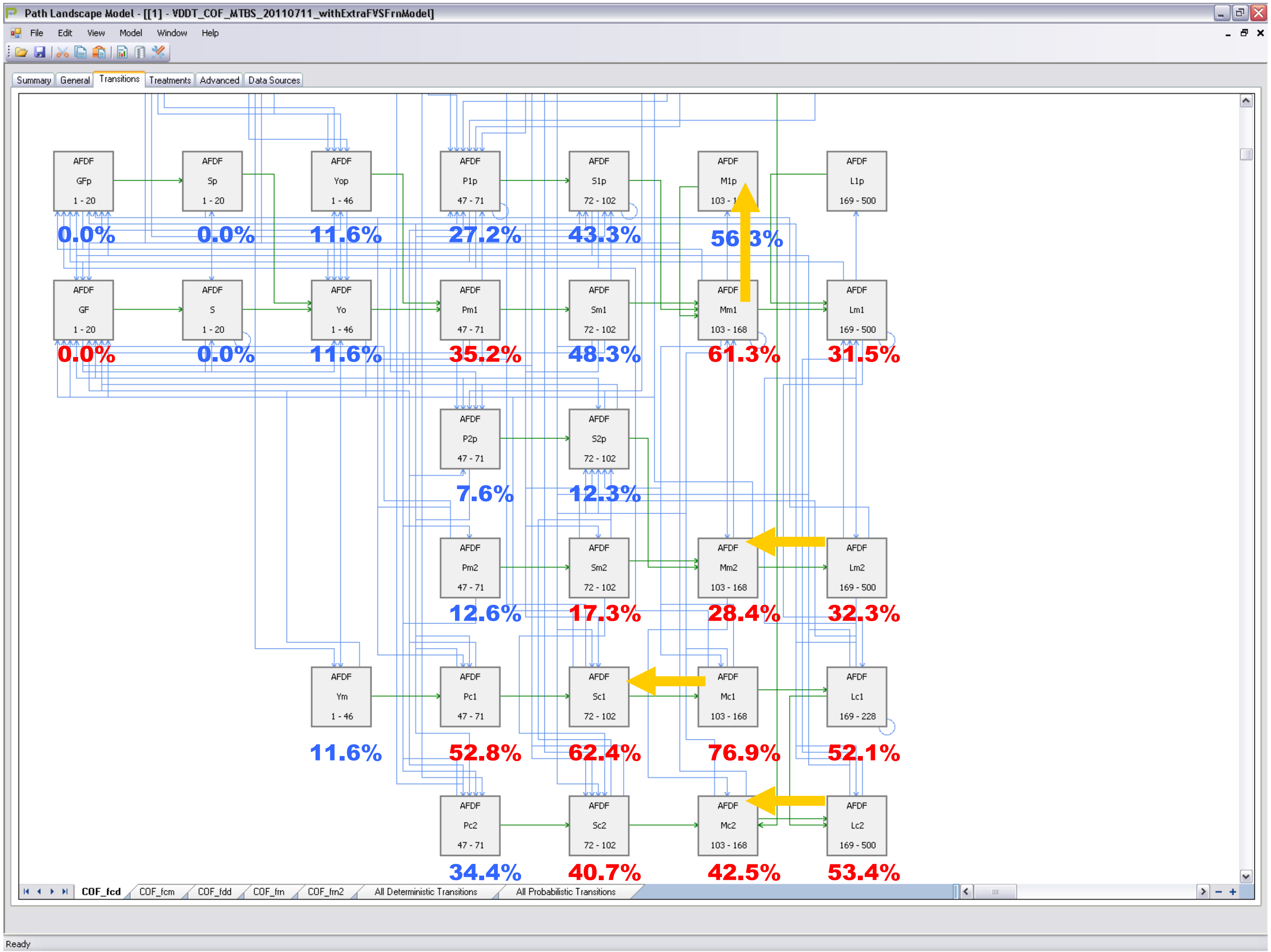
CNF mixed conifer–cool/moist type (COF_fcm)



CNF western redcedar/western hemlock-moist type (COF_frn)



CNF subalpine fir-cool/dry type (COF_fcd)



# ATTACHMENT G

## Determination of Effective Shade Values

For each plot in the IDL riparian survey, we calculated a weighted effective shade at year 0 for a stream oriented 45 deg. Effective shade was weighted proportional to the frequency of stream widths encountered in the stream survey. We then calculated an average value for each of the structural stages; these averages are listed in Table 1 and displayed in Attachments D through F.

Table 1. Average effective shade by size, density, and canopy class.

| Density-Canopy | Structural Size Class | | | | | | |
|---|---|---|---|---|---|---|---|
| | GF | Y | P | S | M | L | G |
| m1 | 0% | 6.1% | 35.2% | 48.3% | 61.3% | 31.5% | 26.5% |
| m2 | | | 12.6% | 17.3% | 28.4% | 32.3% | 27.2% |
| c1 | | | 52.8% | 62.4% | 76.9% | 52.1% | 32.3% |
| c2 | | | 34.8% | 40.7% | 42.5% | 53.4% | 33.1% |

Shaded values in Tables 1 were interpolated from neighboring structural stage classes. Otherwise, values represent averages calculated from the shade simulation results. We used these estimates to develop shade values in Attachments D through F. We used the “p” state classes (which represent post-disturbance conditions) to represent post-thinning shade levels; these were estimated as a nominal (5%) reduction in shade compared to the associated undisturbed shade levels.

Overall, these shade values reflect general trends that we have previously reported concerning the relationship of effective shade and stand structural stage. Generally, shade potential approaches maximal levels as canopy close in small-to-large sawlog stands. When the upper stratum becomes dominated by large-to-giant trees and canopies diversify horizontally/vertically, shade decreases.

Path simulations predicted the area allocated to vegetation states over a 300-year period. Each simulation was repeated 7 times; for each replicate, transitions were determined randomly using the transition probabilities. For each replicate, we used the predictions to calculate the average weighted average effective shade over the entire landscape at each time step.

# Appendix F. Relative Stocking Reduction, Shade Loss and Shade Recovery at Increasing Thinning Intensities Employing a 25 ft Stream-adjacent No Harvest Buffer and a 25 ft Outer Harvest Buffer

Table F-1. Average relative stocking reduction, shade loss and shade recovery at years 10 and 30 using a 25 ft stream-adjacent no harvest zone and an outer 25 ft harvest zone by forest type, stream width, residual stocking level, and relative stocking trend, initial stocking 50% to 70%.

| Forest Type | Stream Width | Residual Stocking | Relative Stocking Trend – Upward[1] | | | | Relative Stocking Trend – Downward[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] |
| NIGF | 10 ft | 35-45 | 27.8 | 0.8% | 99.2% | 99.0% | 23.7 | 3.9% | 95.2% | 94.2% |
| | | 45-55 | 16.0 | 1.1% | 98.8% | 98.5% | 13.7 | 2.7% | 96.5% | 95.7% |
| | | 55-65 | 5.9 | 1.1% | 98.8% | 98.5% | 6.1 | 3.5% | 95.5% | 94.3% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 27.8 | 6.1% | 91.8% | 90.0% | 23.7 | 9.8% | 87.0% | 87.4% |
| | | 45-55 | 16.0 | 5.9% | 91.8% | 90.1% | 13.7 | 9.4% | 87.5% | 87.8% |
| | | 55-65 | 5.9 | 5.2% | 92.5% | 90.6% | 6.1 | 8.6% | 88.2% | 88.2% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 27.8 | 7.7% | 88.4% | 87.3% | 23.7 | 9.1% | 84.9% | 85.4% |
| | | 45-55 | 16.0 | 7.2% | 88.6% | 87.5% | 13.7 | 8.9% | 85.5% | 85.8% |
| | | 55-65 | 5.9 | 6.6% | 89.4% | 87.9% | 6.1 | 8.1% | 86.3% | 86.4% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| CIGF | 10 ft | 35-45 | 19.1 | 5.3% | 94.2% | 94.3% | 18.9 | 5.4% | 93.6% | 93.4% |
| | | 45-55 | 7.7 | 5.3% | 93.9% | 93.3% | 5.9 | 4.0% | 95.0% | 94.3% |
| | | 55-65 | 6.1 | 3.8% | 95.7% | 95.6% | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 19.1 | 8.0% | 87.9% | 88.1% | 18.9 | 7.7% | 87.7% | 88.0% |
| | | 45-55 | 7.7 | 8.0% | 88.0% | 87.9% | 5.9 | 7.1% | 88.6% | 88.6% |
| | | 55-65 | 6.1 | 6.9% | 89.3% | 88.9% | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 19.1 | 7.5% | 85.9% | 86.1% | 18.9 | 7.0% | 85.6% | 86.2% |
| | | 45-55 | 7.7 | 7.4% | 86.1% | 86.2% | 5.9 | 6.6% | 86.6% | 86.8% |
| | | 55-65 | 6.1 | 6.7% | 87.1% | 86.8% | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| SIGF | 10 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 11.2 | 6.4% | 91.4% | 91.9% | -- | -- | -- | -- |
| | | 55-65 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 11.2 | 6.6% | 87.4% | 87.9% | -- | -- | -- | -- |
| | | 55-65 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 11.2 | 5.8% | 85.4% | 86.2% | -- | -- | -- | -- |
| | | 55-65 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| XXWH | 10 ft | 35-45 | 19.1 | 1.0% | 98.8% | 98.6% | 23.6 | 2.0% | 96.9% | 96.9% |
| | | 45-55 | 15.9 | 1.2% | 98.4% | 98.1% | 20.3 | 2.3% | 96.6% | 96.4% |
| | | 55-65 | 5.6 | 0.3% | 99.7% | 99.4% | 7.0 | 2.1% | 96.7% | 96.6% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 19.1 | 2.5% | 95.9% | 95.6% | 23.6 | 2.5% | 94.9% | 95.0% |
| | | 45-55 | 15.9 | 2.2% | 96.1% | 95.8% | 20.3 | 2.6% | 94.6% | 94.5% |
| | | 55-65 | 5.6 | 1.8% | 97.3% | 96.7% | 7.0 | 2.6% | 94.8% | 94.8% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 19.1 | 2.6% | 94.7% | 94.5% | 23.6 | 2.2% | 94.0% | 94.0% |
| | | 45-55 | 15.9 | 2.3% | 95.0% | 94.7% | 20.3 | 2.4% | 93.8% | 93.7% |
| | | 55-65 | 5.6 | 2.2% | 96.0% | 95.4% | 7.0 | 2.3% | 93.9% | 93.9% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| XXDF | 10 ft | 35-45 | 20.3 | 6.8% | 90.1% | 90.9% | 23.5 | 6.4% | 90.7% | 91.1% |
| | | 45-55 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 55-65 | 5.1 | 6.4% | 90.8% | 91.3% | 6.1 | 5.7% | 91.8% | 91.7% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 20 ft | 35-45 | 20.3 | 6.6% | 86.2% | 86.9% | 23.5 | 6.7% | 86.4% | 87.0% |
| | | 45-55 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 55-65 | 5.1 | 6.3% | 87.0% | 87.3% | 6.1 | 6.3% | 87.5% | 87.8% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 30 ft | 35-45 | 20.3 | 5.8% | 84.4% | 85.3% | 23.5 | 5.9% | 84.6% | 85.1% |
| | | 45-55 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 55-65 | 5.1 | 5.6% | 85.3% | 85.6% | 6.1 | 5.6% | 85.8% | 86.0% |
| | | 65-75 | -- | -- | -- | -- | -- | -- | -- | -- |

Notes: [1] – Relative stocking trend determined in unmanaged stands; [2] – Absolute reduction in shade from pre-harvest levels within a 100 ft riparian buffer; 3 – Ratio of shade provided under management to that provided by an unharvested 100 ft riparian buffer at year 10 or year 30.

Table F-2. Average relative stocking reduction, shade loss and shade recovery at years 10 and 30 using a 25 ft stream-adjacent no harvest zone and an outer 25 ft harvest zone by forest type, stream width, residual stocking level, and relative stocking trend, initial stocking over 70%.

| Forest Type | Stream Width | Residual Stocking | Relative Stocking Trend – Upward[1] | | | | Relative Stocking Trend – Downward[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] | Relative Stocking Reduction | Shade Loss Year 0[2] | Shade Recovery Year 10[3] | Shade Recovery Year 30[3] |
| NIGF | 10 ft | 35-45 | 40.4 | 0.5% | 99.2% | 99.0% | 45.0 | 2.9% | 96.2% | 95.4% |
| | | 45-55 | 28.7 | 0.4% | 99.3% | 99.0% | 34.0 | 2.1% | 97.4% | 96.6% |
| | | 55-65 | 16.9 | 0.4% | 99.4% | 99.1% | 25.8 | 2.0% | 97.4% | 96.7% |
| | | 65-75 | 5.2 | 0.3% | 99.5% | 99.1% | 17.3 | 2.7% | 96.3% | 95.4% |
| | 20 ft | 35-45 | 40.4 | 2.7% | 96.3% | 94.7% | 45.0 | 8.2% | 88.5% | 87.7% |
| | | 45-55 | 28.7 | 2.5% | 96.6% | 95.0% | 34.0 | 7.2% | 89.6% | 88.3% |
| | | 55-65 | 16.9 | 2.3% | 96.8% | 95.4% | 25.8 | 6.7% | 90.2% | 88.7% |
| | | 65-75 | 5.2 | 2.0% | 97.1% | 95.5% | 17.3 | 6.5% | 90.0% | 88.9% |
| | 30 ft | 35-45 | 40.4 | 4.9% | 92.2% | 89.8% | 45.0 | 9.7% | 85.4% | 85.0% |
| | | 45-55 | 28.7 | 4.4% | 92.8% | 90.2% | 34.0 | 9.1% | 86.3% | 85.7% |
| | | 55-65 | 16.9 | 4.0% | 93.4% | 90.6% | 25.8 | 8.7% | 86.9% | 86.1% |
| | | 65-75 | 5.2 | 3.6% | 93.8% | 90.9% | 17.3 | 8.0% | 87.3% | 86.3% |
| CIGF | 10 ft | 35-45 | 40.8 | 0.4% | 99.4% | 99.1% | 38.0 | 2.8% | 96.4% | 95.0% |
| | | 45-55 | 29.4 | 0.1% | 99.7% | 99.3% | 25.9 | 2.7% | 96.4% | 95.2% |
| | | 55-65 | 24.8 | 0.5% | 99.2% | 99.0% | 22.4 | 2.0% | 97.1% | 95.5% |
| | | 65-75 | 13.5 | 0.2% | 99.5% | 99.2% | 10.5 | 2.1% | 97.0% | 95.6% |
| | 20 ft | 35-45 | 40.8 | 2.3% | 96.2% | 93.0% | 38.0 | 9.3% | 87.7% | 87.6% |
| | | 45-55 | 29.4 | 2.3% | 96.4% | 93.8% | 25.9 | 8.5% | 88.4% | 88.0% |
| | | 55-65 | 24.8 | 1.8% | 96.5% | 92.7% | 22.4 | 8.8% | 88.4% | 88.2% |
| | | 65-75 | 13.5 | 1.9% | 96.7% | 93.4% | 10.5 | 8.0% | 89.0% | 88.5% |
| | 30 ft | 35-45 | 40.8 | 5.1% | 92.2% | 89.2% | 38.0 | 9.0% | 85.4% | 85.7% |
| | | 45-55 | 29.4 | 4.5% | 93.2% | 90.2% | 25.9 | 8.3% | 86.1% | 86.1% |
| | | 55-65 | 24.8 | 5.0% | 92.1% | 88.7% | 22.4 | 8.7% | 86.3% | 86.4% |
| | | 65-75 | 13.5 | 4.4% | 93.0% | 89.6% | 10.5 | 7.9% | 86.9% | 86.7% |
| SIGF | 10 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 34.4 | 3.0% | 97.1% | 96.5% | 27.0 | 3.9% | 94.9% | 95.3% |
| | | 55-65 | -- | -- | -- | -- | 11.0 | 3.6% | 95.4% | 95.7% |
| | | 65-75 | 17.9 | 2.6% | 97.5% | 96.8% | -- | -- | -- | -- |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 34.4 | 8.3% | 88.2% | 88.0% | 27.0 | 6.7% | 88.9% | 88.6% |
| | | 55-65 | -- | -- | -- | -- | 11.0 | 6.3% | 89.6% | 89.1% |
| | | 65-75 | 17.9 | 7.6% | 88.9% | 88.5% | -- | -- | -- | -- |
| | 30 ft | 35-45 | -- | -- | -- | -- | -- | -- | -- | -- |
| | | 45-55 | 34.4 | 7.9% | 86.0% | 86.2% | 27.0 | 6.3% | 86.2% | 86.4% |
| | | 55-65 | -- | -- | -- | -- | 11.0 | 6.0% | 86.9% | 86.9% |
| | | 65-75 | 17.9 | 7.4% | 86.8% | 86.8% | -- | -- | -- | -- |
| XXWH | 10 ft | 35-45 | -- | -- | -- | -- | 31.7 | 2.1% | 96.7% | 96.4% |
| | | 45-55 | 28.3 | 0.2% | 99.7% | 99.7% | 41.0 | 0.2% | 99.8% | 99.4% |
| | | 55-65 | 13.2 | 0.2% | 99.7% | 99.7% | 23.2 | 0.7% | 98.9% | 98.5% |
| | | 65-75 | -- | -- | -- | -- | 6.2 | 2.0% | 97.0% | 96.2% |
| | 20 ft | 35-45 | -- | -- | -- | -- | 31.7 | 2.5% | 94.8% | 94.5% |
| | | 45-55 | 28.3 | 2.0% | 97.0% | 96.2% | 41.0 | 1.5% | 97.6% | 97.2% |
| | | 55-65 | 13.2 | 2.0% | 97.0% | 96.2% | 23.2 | 1.8% | 96.8% | 96.5% |
| | | 65-75 | -- | -- | -- | -- | 6.2 | 2.7% | 95.0% | 94.4% |
| | 30 ft | 35-45 | -- | -- | -- | -- | 31.7 | 2.3% | 93.9% | 93.7% |
| | | 45-55 | 28.3 | 2.6% | 95.6% | 95.1% | 41.0 | 2.1% | 96.4% | 95.9% |
| | | 55-65 | 13.2 | 2.6% | 95.6% | 95.1% | 23.2 | 2.1% | 95.7% | 95.3% |
| | | 65-75 | -- | -- | -- | -- | 6.2 | 2.5% | 94.0% | 93.4% |
| XXDF | 10 ft | 35-45 | -- | -- | -- | -- | 42.9 | 7.8% | 89.7% | 90.4% |
| | | 45-55 | -- | -- | -- | -- | 17.6 | 6.4% | 90.8% | 91.4% |
| | | 55-65 | -- | -- | -- | -- | 26.7 | 7.3% | 90.4% | 90.8% |
| | | 65-75 | -- | -- | -- | -- | 13.6 | 6.9% | 91.6% | 91.5% |
| | 20 ft | 35-45 | -- | -- | -- | -- | 42.9 | 7.9% | 85.4% | 86.4% |
| | | 45-55 | -- | -- | -- | -- | 17.6 | 6.1% | 86.7% | 87.4% |
| | | 55-65 | -- | -- | -- | -- | 26.7 | 7.7% | 86.3% | 87.0% |
| | | 65-75 | -- | -- | -- | -- | 13.6 | 7.7% | 87.4% | 87.7% |
| | 30 ft | 35-45 | -- | -- | -- | -- | 42.9 | 7.0% | 83.6% | 84.5% |
| | | 45-55 | -- | -- | -- | -- | 17.6 | 5.6% | 84.9% | 85.6% |
| | | 55-65 | -- | -- | -- | -- | 26.7 | 6.9% | 84.6% | 85.2% |
| | | 65-75 | -- | -- | -- | -- | 13.6 | 7.0% | 85.7% | 85.8% |

Notes: [1] – Relative stocking trend determined in unmanaged stands; [2] – Absolute reduction in shade from pre-harvest levels within a 100 ft riparian buffer; 3 – Ratio of shade provided under management to that provided by an unharvested 100 ft riparian buffer at year 10 or year 30.

# Appendix G. Comparison of Shade Loss at Increasing Thinning Intensities Employing a 25 ft Stream-adjacent No Harvest Buffer and a 25 ft Outer Harvest Buffer versus Thinning throughout a 50 ft Buffer

Table G-1. Average effective shade from clearing and thinning throughout a 50 ft buffer and using a 25 ft stream adjacent no harvest buffer, by forest type, stream width, and residual stocking level within thinned portion of the riparian buffer.

| Forest Type / Relative Stocking | Stream Width Class | Unharvested 100 ft Buffer | Cleared to 75 ft Buffer | Cleared to 50 ft Buffer | 0 ft No Harvest Buffer / 50 ft Harvest Buffer | | | | 25 ft No Harvest Buffer / 25 ft Harvest Buffer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Thinned 55 to 65 | Thinned 45 to 55 | Thinned 35 to 45 | Thinned 25 to 35 | Thinned 55 to 65 | Thinned 45 to 55 | Thinned 35 to 45 | Thinned 25 to 35 |
| NIGF | 10 ft | 94% | 94% | 93% | 88% | 82% | 77% | 72% | 91% | 90% | 89% | 87% |
| | 20 ft | 81% | 78% | 75% | 68% | 62% | 55% | 48% | 72% | 70% | 68% | 65% |
| | 30 ft | 67% | 64% | 60% | 55% | 49% | 43% | 37% | 58% | 55% | 53% | 50% |
| CIGF | 10 ft | 90% | 90% | 88% | 80% | 73% | 66% | 59% | 86% | 85% | 84% | 83% |
| | 20 ft | 71% | 69% | 65% | 58% | 51% | 45% | 39% | 62% | 60% | 58% | 56% |
| | 30 ft | 58% | 55% | 51% | 45% | 40% | 35% | 30% | 48% | 46% | 44% | 42% |
| SIGF | 10 ft | 81% | 79% | 76% | 68% | 61% | 53% | 46% | 75% | 73% | 72% | 71% |
| | 20 ft | 59% | 57% | 53% | 47% | 41% | 36% | 30% | 50% | 48% | 46% | 44% |
| | 30 ft | 46% | 44% | 40% | 35% | 31% | 27% | 23% | 38% | 36% | 34% | 32% |
| XXWH | 10 ft | 84% | 83% | 81% | 75% | 69% | 64% | 58% | 80% | 80% | 80% | 80% |
| | 20 ft | 66% | 64% | 60% | 56% | 50% | 45% | 40% | 60% | 59% | 59% | 58% |
| | 30 ft | 53% | 51% | 47% | 43% | 39% | 34% | 30% | 46% | 46% | 45% | 45% |
| XXDF | 10 ft | 70% | 67% | 64% | 59% | 52% | 44% | 37% | 63% | 63% | 63% | 62% |
| | 20 ft | 49% | 46% | 43% | 39% | 34% | 29% | 24% | 42% | 41% | 40% | 40% |
| | 30 ft | 38% | 36% | 33% | 30% | 26% | 22% | 18% | 32% | 31% | 30% | 29% |