EXECUTIVE SUMMARY:
SHADE CONDITIONS OVER FORESTED STREAMS IN THE BLUE MOUNTAIN AND COAST RANGE GEOREGIONS OF OREGON

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INTRODUCTION

The Oregon Department of Forestry's (ODF) water protection rules, as outlined in the Forest Practices Act (FPA) (OAR 629-635 and -640), rely on a number of Best Management Practices (BMPs) to maintain water quality. Riparian Management Areas (RMA) are one example of a BMP that is designed, in part, to achieve water quality standards for temperature by growing and retaining stands with characteristics similar to a mature forest. The rules (OAR 629-630-0100 and 629-640-000) recognize that the age of a mature forest varies by species, but that mature forests "provide ample shade over the channel" and "an abundance of [large wood] in the channel." The rules articulate numeric standards for riparian structures that were assumed to approximate mature riparian forests and, consequently, the functions they provide to streams. These standards were developed by "estimating the conifer basal areas for average unmanaged mature [at age 120] streamside stands" for each geographic region.

RMAs are established on most streams that are adjacent to, or within, a harvest unit boundary. The RMA dimensions vary by stream type and size (Table 1). A landowner has the option to harvest within the RMA, as long as the required basal area is maintained, while maintaining a 20-foot, no-cut buffer zone, as measured from the average annual high water mark, as well as maintaining a specified number of trees per 1000 feet. It is assumed that the State Water Quality Standards (WQS) for stream temperature developed by Department of Environmental Quality (DEQ) will be met by adhering to BMPs, unless monitoring shows otherwise.

The DEQ is required to develop total maximum daily loads (TMDLs) for streams that do not meet the WQS. A key component of DEQ's approach for meeting the temperature standard is developing TMDL allocations for non-point sources to reduce solar loading. Temperature TMDLs are often based on predicted levels of "effective shade" that, in turn, are derived from a prediction of "system potential" vegetation and channel morphology. The DEQ defines system potential vegetation and effective shade in the following manner:

> System potential, as defined in the TMDL, is the combination of potential near-stream vegetation condition and potential channel morphology conditions. Potential near-stream vegetation is that which can grow and reproduce on a site, given: elevation, soil properties, plant biology and hydrologic processes.

> Potential channel morphology is developed using an estimate of width-to-depth ratios appropriate for the Rosgen channel type. System potential does not consider management or land use as limiting factors. In essence, system potential is the design condition used for TMDL analysis that meets the temperature standard. System potential is an estimate of a condition without anthropogenic activities that reduce effective shade. System potential is not an estimate of pre-settlement conditions. Although it is helpful to consider historic vegetation patterns and channel conditions, many areas have been altered to the point that the historic condition is no longer attainable given drastic changes in stream location and hydrology (channel armoring and wetland draining).

A maximum height is predicted for that vegetation type and used, in turn, to predict shade provided to the stream. This, combined with topographic shade, is used to predict the effective shade provided to the stream channel.

The FPA abandoned the use of shade targets with the adoption of the 1994 stream rules, and currently addresses stream temperature issues via riparian stand structure goals. Since TMDLs describe a specific shade target, it is important to make a link between shade provided under the FPA and shade required under TMDLs. Currently, proposed TMDLs predict system potential vegetation and the associated effective shade levels. However, the specific shade levels provided under the FPA have not been well monitored in the field.

The terms canopy, shade, and effective shade are often used interchangeably, but the actual parameter being measured differs. The following provides a distinction between the three commonly used terms:

> *Canopy cover is the percent of the sky covered by vegetation or topography.*
>
> *Shade is the amount of solar energy that is obscured or reflected by vegetation or topography. It is expressed in units of energy per unit area per unit time, or as a percent of total possible energy. Shade-producing features will cast a shadow on the water, while canopy cover may not.*
>
> *Effective shade is a term commonly used to distinguish between vegetation that does not provide shade to a stream and vegetation, combined with topography, that does provide shade to the stream.*

For the purposes of this study, the term "shade" is used to refer to vegetation and topography as measured with a hemispherical photography that provides shade to the stream. For this study, shade, cover, and riparian stand structural data were collected across a range of forest stand conditions to determine the range in shade and riparian stand conditions and if the riparian stand conditions that result from harvesting can be directly linked to shade over the stream.

MONITORING OBJECTIVES AND QUESTIONS

OBJECTIVES

The specific objectives of the project were to:

1. Document the ranges of shade conditions that occur under a variety of riparian stand structures and disturbance regimes in northeast and northwest Oregon.

2. Document the relationships between shade and riparian stand structure, geomorphology, forest management, and other disturbances.

QUESTIONS

In order to meet these objectives, the following questions were addressed:

1. What are the ranges in shade conditions over Blue Mountain and Coast Range forested streams and how do they compare between harvested and unharvested stands?

2. Do particular Riparian Management Area prescriptions in harvested stands result in different average shade conditions?

3. What are the relationships among shade and channel and valley morphology?

4. How do disturbances, other than harvesting, affect shade on forested streams?

5. What are the relationships between riparian stand characteristics and shade?

STUDY DESIGN

This study focused on the Blue Mountain and Coast Range georegions as described in the Oregon Department of Forestry forest practices rules (OAR 629-635-220) (Figure 1). Thirty-one sites in the Blue Mountain georegion and 30 sites in the Coast Range georegion were selected for a total of 61 sites.

Plots were established on both sides of the stream at each site. Plots were 100 feet wide and varied in length between 500, 800, and 1000 feet. All trees ?6 inches diameter at breast height in the plot were measured for species, distance from stream, and diameter. The total height and height to the base of the live crown were measured on a subset of trees (every 5th tree). The buffer width, slope of riparian area, and floodprone width was measured every 200 feet. Reach shade was calculated from fish-eye photos (Figure 2)

taken every 100 feet along the stream and averaged for the reach. Cover was also measured with a densiometer.

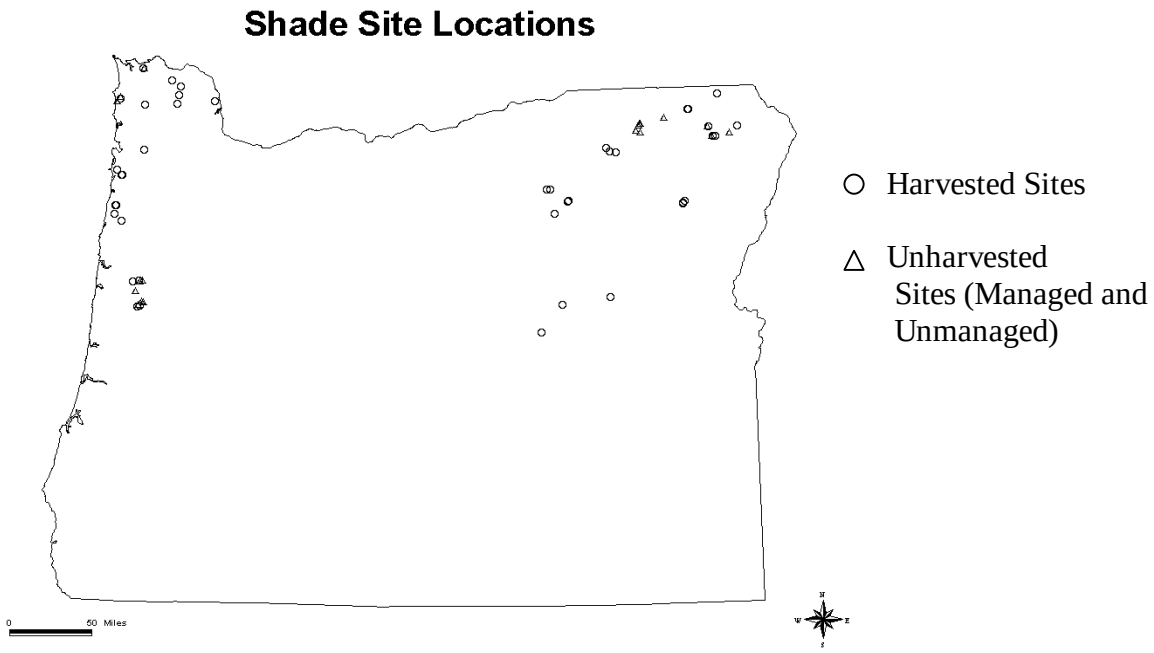

Figure 1. Locations of harvested and unharvested study sites. Blue Mountain georegion includes the northeast Oregon sites and the Coast Range georegion sites are included in the western Oregon sites.

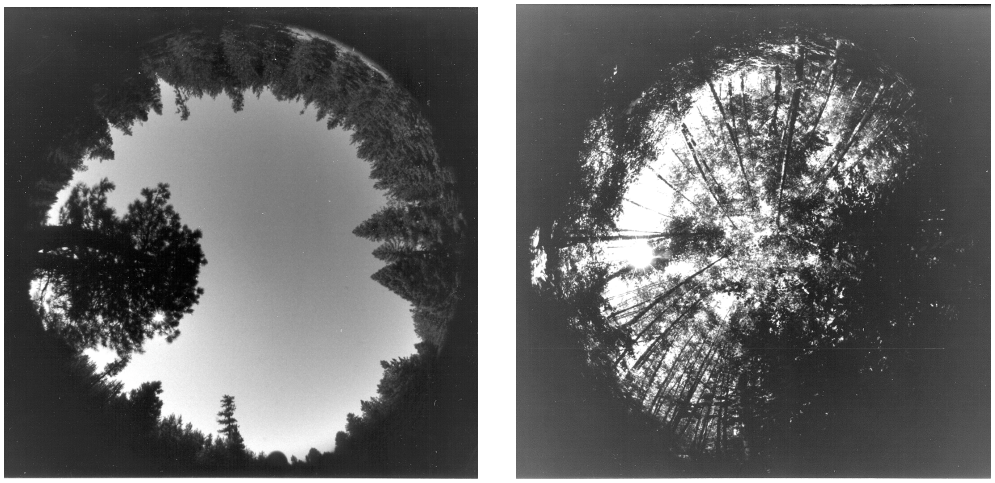

Figure 2. Examples of hemispherical (fish-eye) photographs taken at a site in the Blue Mountain georegion (left) and at a site in the Coast Range georegion (right).

STRENGTHS AND LIMITATIONS OF THE STUDY

This study was unique in that it specifically examined units harvested according to the 1994 Oregon Forest Practices Rules. It also utilized hemispherical photography to measure shade, which is considered to be a reliable and repeatable measurement of canopy characteristics that can be used to derive shade. Hemispherical photographs were paired with a more traditional means of measuring cover, the densiometer, which facilitated comparison between the two methods and to other studies using the same methodologies. Another strength of the study was its applicability to other in-progress TMDLs, which have concentrated thus far in these two georegions.

Data collection was stratified so that shade across a range of stand conditions and stream sizes could be investigated within each georegion while attempting to account for other confounding variables (valley form, aspect, natural and anthropogenic disturbance, etc.). However, the lack of random selection limits the ability to apply statistical tests that can be extrapolated to the population as whole. For example, the resulting sample had a limited number of large and low-gradient streams, unharvested sites with an east/west aspect and degrees of disturbance. In addition, comparisons between harvested and unharvested streams were limited due to the resulting sample. For example, in the Blue Mountain georegion, the unharvested sites were almost completely comprised of white-fir stands without grazing, while the harvested sites were comprised of a mix of stand types that had been grazed. Finally, since the comparison between harvested and unharvested stands is not pre-harvest versus post-harvest, observed differences in shade between harvested and unharvested may be attributable to differences in site conditions, rather than the harvest itself.

SITE CHARACTERISTICS

Sites were characterized as either harvested or unharvested. Unharvested sites were harvested in 1998. Unharvested sites were predominantly unmanaged (eight and seven in the Blue Mountain and Coast Range georegions, respectively). However, some of these unharvested sites had historic management activity (two in each georegion). Therefore, the stand ages are described as follows.

HARVESTED SITES. Blue Mountain harvested stands ranged from 26-123 years and averaged 68 years. Coast Range harvested stands ranged in age from 35-125 years and averaged 65 years. In the Blue Mountains the long history of selective harvest practices and more frequent fires makes estimates of stand age more difficult. Because harvest practices (mostly clearcuts) and disturbance regimes (stand replacement fires) in the Coast Range georegion tend to reset the entire stand age, overstory tree ages are likely to be a good estimate of the time since the last harvest entry or large-scale disturbance.

UNHARVESTED SITES. At each site, one or two overstory trees were cored to estimate stand age. The length of the increment borer prevented accurate age estimates on the largest trees, so overstory age is likely underestimated in some stands. According to these data,

in the Blue Mountain georegion, unharvested ages ranged from 25-160 years and averaged 65 years. Unharvested overstory trees in the Coast Range georegion ranged in age from 32-120 years and averaged 90 years. Thus, unharvested stands are defined as those that have not been disturbed for approximately 25 years and up to 160 years.

A total of 31 sites in the Blue Mountain and 30 in the Coast Range georegions were monitored. There were 21 harvested sites in each georegion. There were 10 unharvested sites in the Blue Mountain georegion and nine unharvested sites in the Coast Range georegion. In both georegions, the harvested and unharvested samples were dominated by small and medium streams. Though this is likely to be representative of stream sizes across the landscape, especially those adjacent to harvest units, the sample limits conclusions about large streams in particular. Harvested sites were largely represented by large industrial ownership (60%). Sixty percent (11 sites) of the unharvested sites were on federal ownership and 40% (eight sites) were on industrial managed land.

In both georegions, and for harvested and unharvested stands, the majority of the sites were in narrow, steep or moderately steep, V-shaped valleys. In the Blue Mountain georegion, substantial differences existed in disturbance and stand characteristics between harvested and unharvested sites (Table 1). Specifically, the majority of the harvested sites were also grazed and evenly distributed between pine and fir stands, while the unharvested sites were predominately not grazed and were on predominately white fir stands. It is critical to understand that these inherent differences between harvested and unharvested sites creates confounding results when trying to interpret cause and effect relationships between one of these factors and shade. This is a limiting factor of this study and tempers the conclusions of this paper with regard to harvest effects on shade in the Blue Mountain georegion.

In the Coast Range, disturbance other than harvesting and dominant overstory stand characteristics were similar between harvested and unharvested sites, with the exception of blowdown. For harvested sites, 32% of sites had greater than 10% blowdown, while none of the unharvested sites had greater than 10% blowdown (Table 1).

The majority of sites had harvest units on both sides of the stream (two Blue Mountain sites were one-sided) that were thinned in the Blue Mountain georegion and clearcut harvested in the Coast Range georegion. None of the RMAs observed in this study utilized the general prescription to manage RMAs to Forest Practices Act standard targets for basal area. The majority of the Blue Mountain sites utilized a site-specific plan while the majority of the Coast Range sites utilized a no-cut buffer RMA prescription.

A high variability in total basal area within riparian areas was observed and is consistent with findings from other studies (Nierenburg and Hibbs 1999, Pabst and Spies 1999, Hairston-Strang and Adams 2000) and ODF monitoring projects (Dent 2001). The basal area analysis indicated that, on average, basal area retained on these study sites was in excess of what is allowable from a basal area prescription on small streams in the Blue Mountain (+33%) and Coast Range (+22%) georegions. On average, retained basal area on medium and large streams did not substantially exceed requirements on these study

sites (4-10%). It is likely that a basal area prescription would have been applied to a different kind of riparian stand (conifer-dominated), result in a different stand structure, a more variable buffer width, and thus, potentially produce different shade levels. Therefore, results from this study are most appropriately applied to sites managed with a site-specific plan in the Blue Mountain georegion or a no-cut buffer in Coast Range georegion.

Table 1. Percent and number of sites with disturbance, other than harvesting, overstory species/type, and valley form by georegion.

SITE CHARACTERISTICS	BLUE MOUNTAIN GEOREGION		COAST RANGE GEOREGION	
	HARVESTED % of sites and (n)	UNHARVESTED % of sites and (n)	HARVESTED % of sites and (n)	UNHARVESTED % of sites and (n)
Disturbance Other Than Harvesting				
Grazed	81% (17)	20% (2)	0%	0%
Blowdown (≥10%)*	14% (3)	0%	32% (6)	0%
Recent Fire	24% (5)	0%	5% (1)	0%
Insect & Disease (≥10%)*	24% (5)	20% (2)	0%	0%
Dominant Overstory Species/Type				
White Fir	29% (6)	80% (8)	-	-
Ponderosa Pine	38% (8)	0%	-	-
D.-Fir/E. Spruce	33% (7)	20% (2)	-	-
Conifer	-	-	26% (5)	33% (3)
Hardwood	-	-	69% (13)	56% (5)
Mixed	-	-	5% (1)	11% (1)
Valley Form				
Steep/Moderate V-shaped Valley	76% (16)	100% (10)	79% (13)	89% (8)

*Greater than, or equal to, 10% of the total stems within 100 feet of the stream were blown down or affected by insects and/or disease.

WHAT ARE THE RANGES IN SHADE CONDITIONS OVER BLUE MOUNTAIN AND COAST RANGE FORESTED STREAMS AND HOW DO THEY COMPARE BETWEEN HARVESTED AND UNHARVESTED STANDS?

Average stream shade in the Blue Mountain georegion ranged from 28-83% and 63-84% for harvested and unharvested sites, respectively. Average stream shade in the Coast Range ranged from 51-89% and 72-95% on harvested and unharvested sites, respectively. Large streams tended to have 9% and 5% lower shade than medium or small streams in the Blue Mountain and Coast Range georegions, respectively (Figure 3).

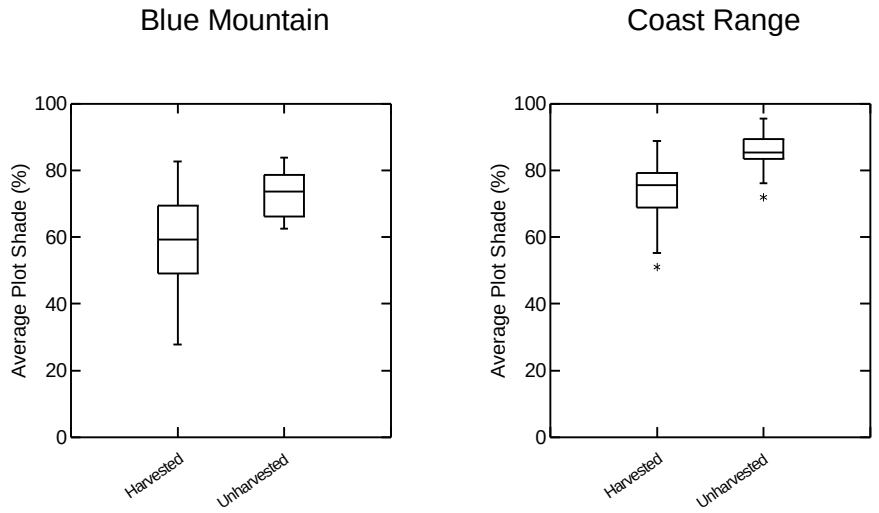

Figure 3. Stream shade under harvested and unharvested RMAs by georegion.

Average stream shade in harvested stands was 15% and 11% less than unharvested stands in the Blue Mountain and Coast Range georegions, respectively. In the Blue Mountain georegion, the average shade was 58% and 73% for harvested and unharvested streams, respectively. In the Coast Range georegion, the average shade was 73% and 84% for harvested and unharvested streams, respectively. Differences in shade between harvested and unharvested reaches ranged from 44% lower to 6% greater and 38% lower to no difference in the Blue Mountain and Coast Range georegions, respectively. Harvested stands also had greater variability than unharvested stands for both georegions. While the upper ranges of shade are comparable to unharvested stands, shade over streams adjacent to harvested stands had much lower minimum shade levels (-21%).

Small harvested streams had 17% and 13% less shade on average than unharvested streams, while medium streams averaged 12% and 19% less shade in the Blue Mountain and Coast Range georegions, respectively. The greatest difference between harvested and unharvested stands was observed with large streams (30% and 25% in Blue Mountain and Coast Range georegions, respectively). While the sample size is considered adequate to describe changes across all streams, breaking the sample across stream size categories restricts the strength of statements by stream size, especially for large streams.

The results regarding small streams are supported by another ODF monitoring project (Dent 2001), while results regarding medium and large streams are not. Dent collected *cover* data before and after harvest. Decreases in *cover* were found with small streams after harvest (-12%), while observed changes in cover over medium streams were not statistically significant (-7%). No detectable changes in cover (-1%) were observed over large streams.

Overall, the sample in unharvested stands was not sufficient to capture the full range of variability. This is especially true in the Blue Mountain georegion, and when attempting to analyze the data by stream size or stand type. All riparian stands were unlikely to exceed 200 years of age, and are considered to have characteristics most closely

resembling the stem exclusion or understory reinitiation stage of stand development (Oliver and Larson 1996). Whether these stages, or a stage more like old growth conditions, are the desired "reference" condition must be given careful consideration. Further identification of and data collection in "reference" stands would be valuable for future monitoring efforts.

Cover data were a good approximation for shade (r^2=76%), but tended to over-predict shade at higher values (>70%) and under-predict at low values. It is possible that orienting cover measurements towards the angle of greatest solar exposure (angular canopy density) may improve this relationship. Correlation between these two systems may also improve if hemispherical photographs are processed in such a way that their angle of view mimics those of the densiometer (Englund et al. 2000).

Oregon Department of Forestry shade data were comparable to other studies in Coast Range/Cascade regions, though ODF cover data was consistently higher. This may be due to measurement differences. Cover data from the other studies were dominated by a technique that oriented measurements towards the greatest solar exposure, whereas ODF measurements were vertical. In comparison to other studies in easterly, intermountain regions, average ODF cover data were slightly higher, but had lower minimum values. Shade data was not available for comparison in this region.

DO PARTICULAR RIPARIAN MANAGEMENT AREA PRESCRIPTIONS IN HARVESTED STANDS RESULT IN DIFFERENT AVERAGE SHADE CONDITIONS?

Overall, the RMA prescription applied, and buffer width retained, did not explain observed variation in stream shade on harvested stands. Whether or not a stand was harvested appeared to be more related to shade.

WHAT ARE THE RELATIONSHIPS AMONG SHADE AND CHANNEL AND VALLEY MORPHOLOGY?

Overall, there were no strong relationships between shade and floodprone width or gradient. General trends of higher shade on north/south flowing streams and increasing average shade with decreasing stream size, decreasing bankfull width, increasing incision, and increasing valley width were observed. However, significant overlap in the ranges in shade and a small sample size of large, wide, low-gradient streams decreased the explanatory power of these analyses. The data were dominated by streams less than 25 feet wide at bankfull flows, and were surrounded by trees that were at least as tall as the channels were wide. Thus, a greater sample size of large streams would be necessary to more fully investigate the role of stream size in predicting shade.

HOW DO DISTURBANCES, OTHER THAN HARVESTING, AFFECT SHADE ON FORESTED STREAMS?

Blowdown was the only significant disturbance mechanism observed, other than forest harvest in the Coast Range. Furthermore, blowdown occurred predominately in

harvested stands. In both georegions, whether or not a stand was harvested appeared to explain shade levels much more than the percent of total RMA trees blown down. In the Blue Mountains, more than 20% of the trees in a stand could be influenced by insects or disease, but like blowdown, shade appeared to be more related to harvest entry. Trees affected by insects or disease constituted less than 5% of the total stems in Coast Range RMAs, and did not appear to influence stream shading.

The lowest average Coast Range shade conditions were observed, however, in a stand with nearly 40% blowdown. Overall, the average shade for stands with at least 10% of trees blown down was 7-8% lower than other stands in both georegions.

A plot was identified as being affected by fire only if there was recent, obvious evidence that a fire had occurred there. Five sites were recently burned in the Blue Mountains, and averaged 15% less shade than all other stands. However, these lower shade conditions may be explained by burned sites being comprised only of harvested sites, most of which were pine stands which were also observed to have lower average shade conditions (see discussion of riparian stand characteristics and shade). Only one site in the Coast Range was recently influenced by fire.

In the Blue Mountains, more than 20% of the trees in a stand could be influenced by insects or disease, but like blowdown, shad appeared to be more related to harvest entry. Trees affected by insects or disease constituted less than 5% of the total stems in the Coast Range RMAs, and did not appear to influence stream shading.

Grazing was the final disturbance mechanism investigated. It is common in the Blue Mountains for land to be utilized for both forestry and cattle grazing. A site was identified as "grazed" if there was obvious evidence that cattle were or had recently been present (animals visible, fresh droppings). Those sites that had been grazed averaged 19% less shade than those that had not. Sites that were grazed, however, were dominated by harvested pine stands and east/west aspects, both of which tended to have lower shade levels. Nonetheless, it is important to recognize how common it is in this georegion for multiple uses to occur on a given site, and that observed shade was a result of the combined effects of forest and range land management practices.

The influence of beaver was not captured with this study. It is possible that beaver activity had been present on a portion of the Blue Mountain sites and on many of the Coast Range sites and that the effects were not identified and documented in the field as such. The expectation is that sites influenced by beaver tend to have lower shade as a result of both felling of trees and channel widening from dam construction.

WHAT ARE THE RELATIONSHIPS BETWEEN RIPARIAN STAND CHARACTERISTICS AND SHADE?

In the Blue Mountains, the dominant overstory may play a more important role in influencing shade than observed in the Coast Range. White fir-dominated stands

averaged 71% shade, Douglas-fir/Englemann spruce stands averaged 61% shade, while pine stands averaged only 51% shade. Harvest entry did not appear to influence stream shade in Douglas-fir/Englemann spruce stands, but harvested white fir stands averaged 11% lower shade than unharvested white fir stands. Unharvested pine stands were not sampled (Figure 4).

The riparian stands sampled in the Coast Range were predominately hardwood, though conifer and mixed stands were also represented. Average shade conditions between these stand types were comparable (72-79%). Harvested conifer stands, however, averaged 20% less shade than unharvested conifer stands while this difference was only 11% in hardwood stands (Figure 4).

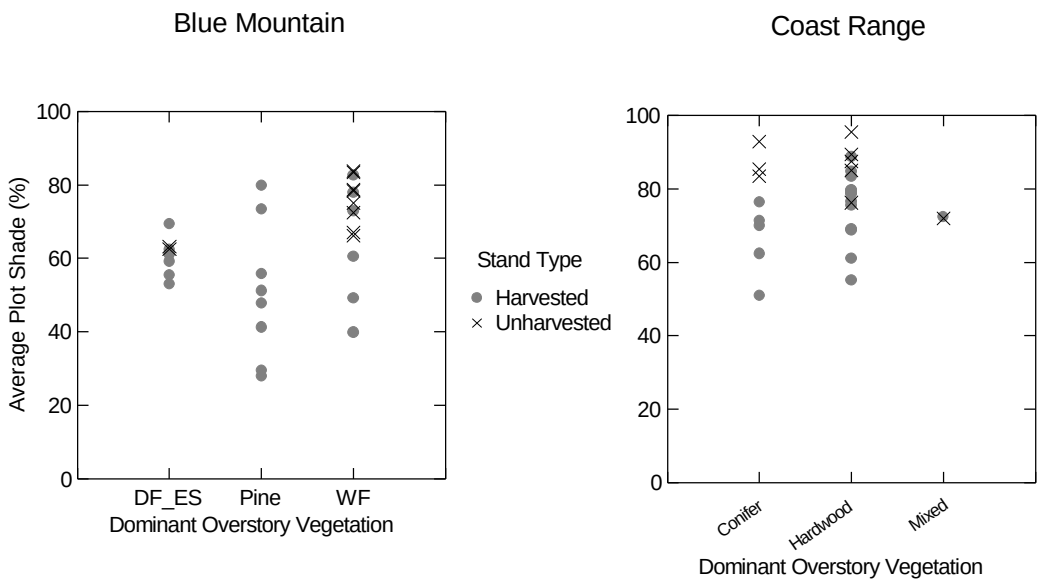

Figure 4. Dominant overstory, shade, and harvest designation by georegion. DF_ES = Douglas-fir/Englemann spruce, WF = White fir.

Shrubs between 3 and 10 feet tall contributed at least 7% and 9% shade in the Blue Mountain and Coast Range georegions, respectively. The greatest shrub contributions, at least 16% in the Blue Mountains and at least 30% in the Coast Range, were observed in harvested stands suggesting understory vegetation may play a greater role once a stand is harvested. These results underestimate the contribution of shrubs, since the photos did not capture shade less than 3 feet tall and could not account for understory vegetation that was taller than 10 feet (separate from the overstory).

In both georegions, unharvested stands tended to have lower live crown ratios, greater average shade, tree heights, basal area, and trees per acre. A given shade value, however, was produced by a range of stand conditions. Though there was a general association between higher stocking, taller trees, lower live crown ratios and high shade, a simple and accurate predictive tool between a single stand characteristic and shade was not

observed. There was some evidence to suggest that greater basal area tree retention beyond 40 feet (Blue Mountain georegion) and 80 feet (Coast Range georegion) resulted in higher shade.

A relationship between shade and tree height was not evident in either georegion or aspect. For north/south flowing streams in the Coast Range, there was a slight positive trend between average tree height and shade. Grouping by ODF stream size did not provide any further explanation of shade. It is likely that the lack of explanatory power is a result of a sample of sites with tall trees (>40 feet) and narrow channels (<25 feet). Additionally, due to the meandering nature of streams the influence of valley aspect on stream shade will vary within a reach as the aspect of the channel itself varies.

Taking stream valley aspect into account identified that shade conditions over Blue Mountain east/west flowing streams were strongly correlated with both basal area and trees per acre. The live crown ratio did not refine the relationship. This may be due to the long history of selective harvest in the Blue Mountains. Selective harvest is likely to result in a mix of live crown ratios and high variability in the stand conditions represented by a given basal area, whereas even-aged management in the Coast Range should result in more homogenous stand conditions. The relationships of shade to basal area and trees/acre in the Coast Range were not as strong. Shade over north/south facing streams was not well correlated with any stand characteristics in either georegion (Figures 5 and 6).

PROPOSED MODELS

For each georegion, the most promising variables from the preliminary analysis were tested in a multiple linear regression model. The relationship of average shade to average live crown ratio and RMA basal area per acre (north and south sides individually) was tested using multiple linear regression. For east/west flowing Coast Range streams, results indicate that average shade could be expressed as a function of average live crown ratio and basal area on the south RMA. While the model did not identify basal area in the north RMA as a *predictor* of shade, that does not infer that trees on the north side do not *contribute* to shade. For example, streams tend to meander and, therefore, do not run in an exact east-west line. Consequently, trees on both sides of the stream are important contributors to shade. Furthermore, streamside vegetation serves important functions, other than providing stream shade, and these functions must be provided from both sides of the stream.

In a general sense, the model infers the following: that shade is sensitive to the interaction between stand density and canopy structure on the south side of an east/west flowing stream. Furthermore, shade appears to follow expected stand development characteristics where more open-grown stands (low basal area) tend to have higher live crown ratios and lower shade than dense stands (high basal area) with low crown ratios (Oliver and Larson 1996). More specifically, the conditions in the Coast Range most likely to achieve 80% or greater shade are those stands with live crown ratios of

approximately 30% and basal area per acre within 100 feet of bankfull in the southern RMA at, or exceeding, 150 sq. ft./ac. Live crown ratios less than 30% are considered indicative of poor vigor.

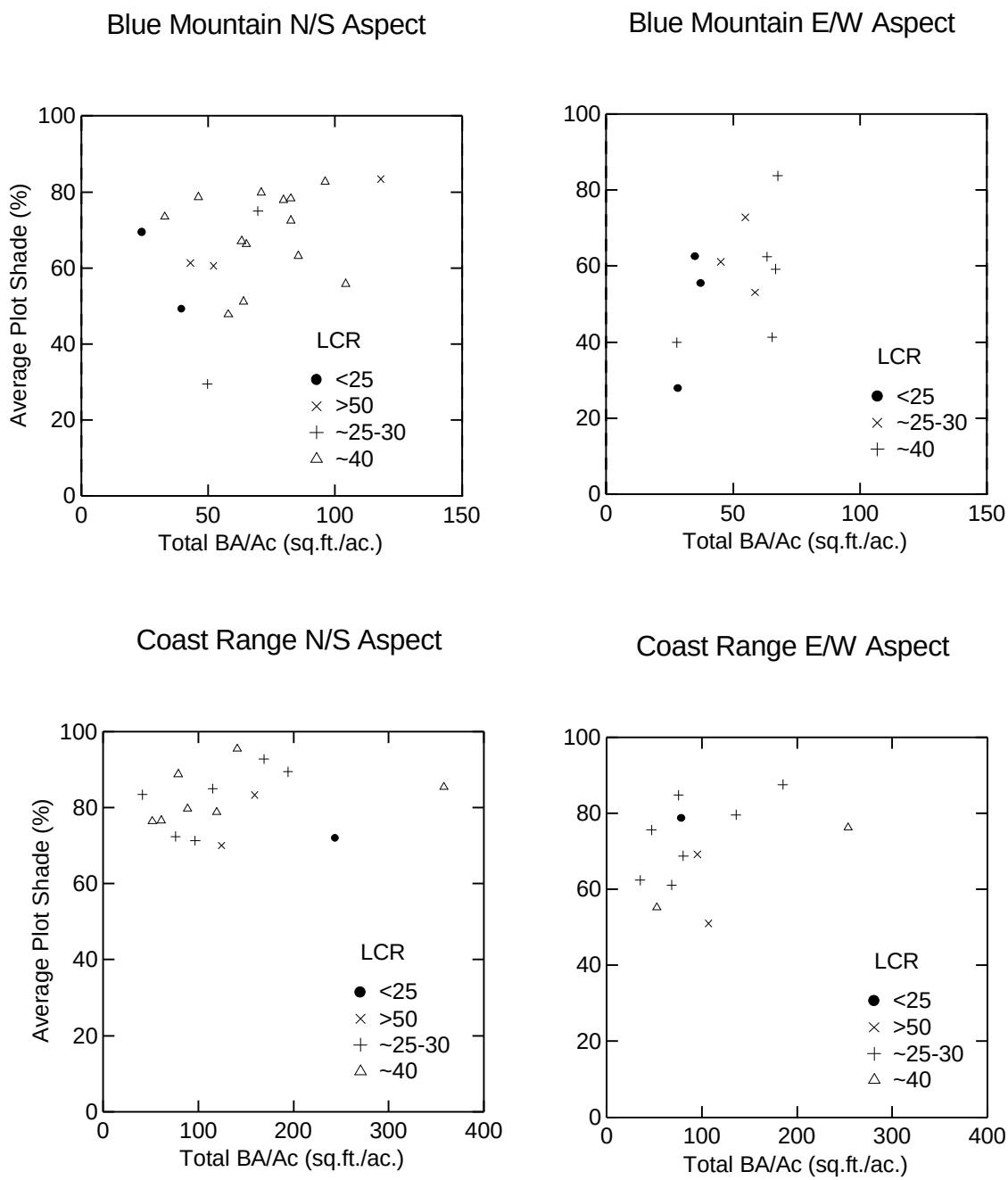

Figure 5. Shade versus basal area per acre for each georegion by aspect and live crown ratio (LCR).

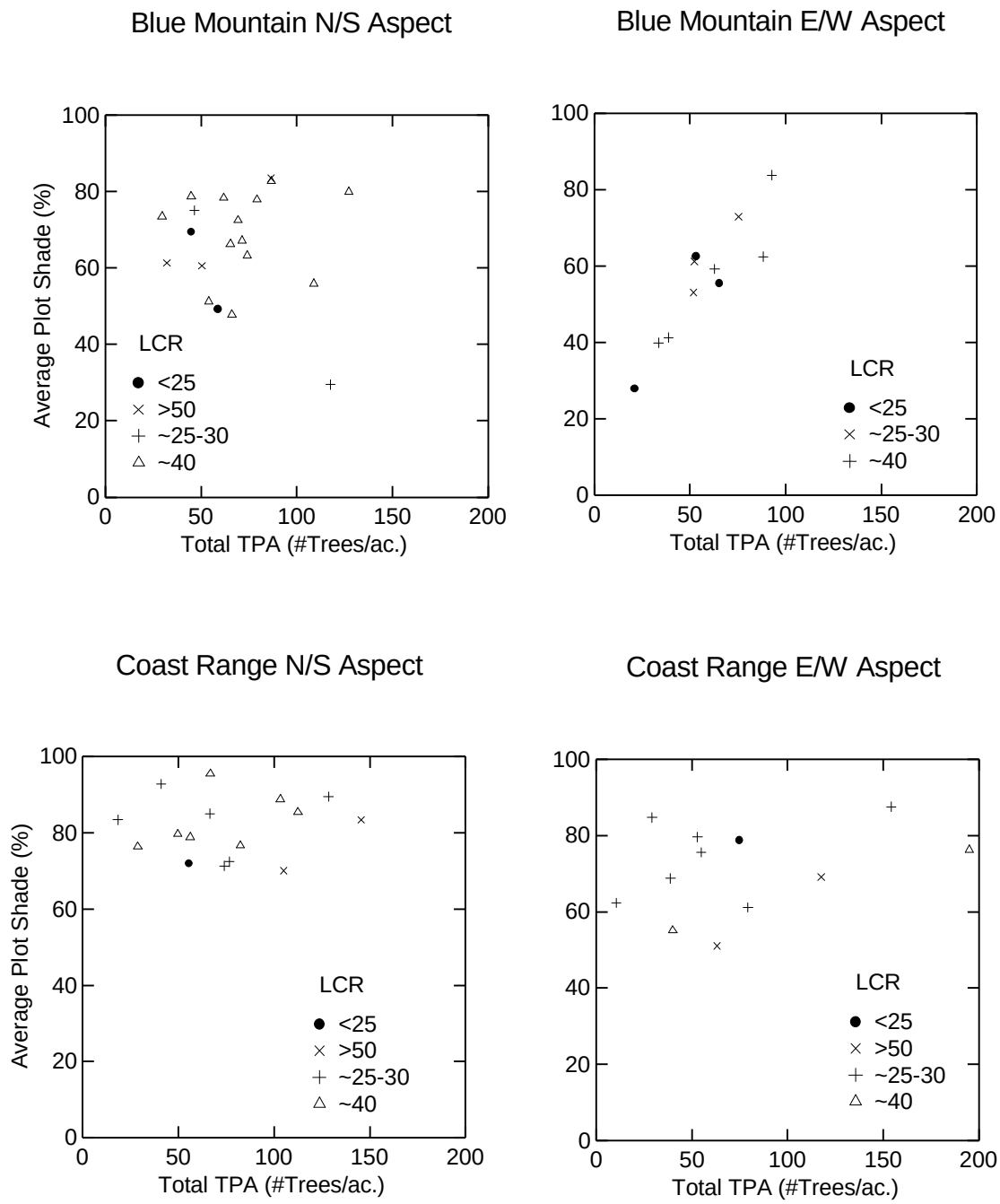

Figure 6. Shade versus trees per acre for each georegion by aspect and live crown ratio (LCR).

A different model was tested in the Blue Mountains, consisting only of trees per acre on both the north and south sides of the stream as predictors of average shade conditions over east/west flowing streams. In this case, the number of trees on both the north and south sides of the stream contributed to shade (both $p=0.001$, $r^2=0.83$).

Like the Coast Range model, this model suggests that stand structure plays an important role in determining the range of shade over streams and how this range will be affected by adjacent forest harvest activities. Where riparian areas consist of a dense stand of small trees, shade is likely to be high and more noticeably influenced by harvest in the RMA. Furthermore, less dense stands with larger trees are likely to have lower shade conditions overall, and reductions in the number of trees are not likely to result in as great a change in shade. Finally, the lack of an identified model to predict shade over north/south flowing streams does not suggest that a relationship between stand or topographic characteristics and shade is nonexistent.

Both the Blue Mountain and Coast Range models require further testing with a greater sample size and range of stream sizes and stand conditions. Specifically, it would be desirable to test this model under conditions where the RMA was harvested to FPA minimum basal area requirements. Also, both models may be limited in that they are linear. It seems likely that there would be an asymptotic relationship between shade and stand characteristics, and a wider range of stand conditions may permit investigation of such a modification. Further investigation of the factors that may influence shade over north/south flowing streams is also recommended.

Finally, the importance of overall stand structure in influencing stream shade (as opposed to a single variable) cannot be overemphasized. By stand structure, we refer to combinations of basal area, stand density (trees/acre), species composition, average stand diameter (QMD), and live crown ratios. Furthermore, the interaction between stand structure and aspect are clearly important when predicting shade. The fact that the Coast Range model did not identify basal area on the north RMA as *predictive* does not indicate that trees on the north sides of stream do not *contribute* to shade in that georegion.

Data collection for this study was in second- or third-rotation stands estimated to be less than 200 years in age, and are thought to be best described as representing the stem exclusion and understory re-initiation stages of stand development. Shade is expected to increase as a stand grows after harvest or disturbance, and is maximized during the stem exclusion stage. As the stand moves into the understory reinitiation stage, and later into old growth, light filtering through the forest canopy will generally increase (must do so to allow for reinitiation) and fluctuate as overstory trees succumb to age or disease, as suppressed trees are released, or die, and disturbances create openings.

The Oregon Department of Forestry forest practice rules abandoned the use of a shade standard, in part, due to the difficulties of identifying which trees should be retained to provide the desired shade conditions after harvest. As this study shows, shade is a function of the overall stand structure. Managers must consider carefully what their objectives are for stream shading in relation to stand structure and the myriad of other

"goods" produced by a riparian stand. If the objective is to maximize shade, this would suggest promoting stands in the stem exclusion stage across the landscape. This may not, however, meet other goals, such as recruiting large woody material to act as stable key pieces in the stream.

RECOMMENDATIONS

FURTHER ANALYSIS

One of the original objectives of this study was to collect data that would inform the Total Maximum Daily Load (TMDL) process, particularly as it pertained to development of "shade" targets for basins listed as water quality limited for temperature. A related objective was to evaluate if the shade conditions provided under the Forest Practices Act were likely to be effective at meeting water quality standards for stream temperature.

> *Recommendation #1: Shade Target and Forest Practices Effectiveness Analysis*
> Evaluate if shade, as measured on these 61 sites, meets DEQ shade targets, analyze the accuracy with which the DEQ "shade calculator" predicts shade on these 61 study sites, and evaluate if the measured values are predicted to meet water quality standards.

MONITORING

Most of the private forestland in eastern Oregon is managed for multiple uses. Specifically, lands are commonly managed for both forestry and range. Furthermore, this study attempted to evaluate effects of current forest practices through a comparison of harvested sites and unharvested sites. Inherent differences between harvested and unharvested sites, particularly in eastern Oregon, tempered the conclusions that could be drawn from the analyses. Finally, this study, and previous ODF monitoring projects, have focused on the period immediately following harvest on a reach scale.

> *Recommendation #2: Monitoring Multi-use Practices in Eastern Oregon*
> Develop a methodology that is sensitive to the variety of range practices that occur throughout eastern Oregon.
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> *Recommendation #3: Reference Conditions*
> Monitor a range of "reference" conditions that better represent the range of stand conditions, channel, and valley characteristics observed on unharvested stands. Especially lacking in this study were pine-dominated reference sites. Stands should represent the goals of the Forest Practices Act (mature riparian forest). Reference sites are valuable for quantifying a range of conditions to which sites managed under current forest practices can be compared. This approach is considered trend monitoring and is seen as distinct from an evaluation of effectiveness.

Recommendation #4: Future Effectiveness Monitoring Design and Focus
Use pre- and post-harvest monitoring to determine effectiveness of current forest practices. Collect further shade, basal area, stand density, and live crown ratio data in the Blue Mountain and Coast Range georegions to confirm or reject the trends identified in this analysis. Use these data to develop predictive equations between shade and stand characteristics. Test proposed shade models (including DEQ's shade calculator and those proposed in the final report) over a wider range of stand conditions, channel and valley widths, and greater sample size. Specifically, identify sites where the riparian area has been managed using the general prescription for standard basal area targets.

Recommendation #5: Evaluate Changes in Shade Over Time and Space.
While decreases in shade may be greatest on small streams, small streams may also have the most rapid shade recovery rates. Furthermore, how does shade vary at reference sites over time and from natural disturbance? The monitoring to date has focused on a reach scale. Expand the questions to address spatial/temporal distribution on a watershed scale.

FIELD METHODS

This study collected detailed and extensive information in riparian areas. Although the process provided valuable data, it was costly and time consuming.

Recommendation #6: Investigate Correlation Between Shade and Other Stand Characteristics
Investigate if either live crown ratio can be related to more commonly collected stand data or if a different, more readily available parameter can help explain shade conditions in Coast Range stands. Future data collection efforts should consider the relationship between shade, tree density (basal area or trees per acre) and crown radius. Crown radius is more commonly collected with silvicultural inventories, and is more readily predicted from tree diameters.

Recommendation #7: Investigate Correlation Between Shade and Other Timesaving Plot Designs
Investigate different plot sampling techniques for both riparian characteristics and shade. The goal should be to sample riparian characteristics more efficiently with some type of sub-sample in a way that is coordinated with other trend and effectiveness monitoring. Ideally, the plot design would correlate stand characteristics with hemispherical photos. The design should put shade variability in the context of multiple scales (reach, watershed, landscape).

POLICY

The conclusions from this report were limited, primarily due to confounding effects that could not be adequately addressed with the study design. However, the study identified some key findings to be considered by the forest practices policy staff. Forest management in northwest and northeast Oregon resulted in a wide range of riparian stand structures and shade conditions. However, the riparian conditions resulted in consistently lower shade than what was observed on unharvested sites. While the unharvested sites did not provide ideal "reference" conditions (inherent site differences other than harvesting), some of the findings were consistent with findings from ODF technical report #12 (Dent 2001). Specifically, both studies concluded that harvested sites had less shade than unharvested sites, particularly on small streams and, to some degree, on medium streams.

An analysis of shade as a function of stand structure indicated that basal area alone was not predictive for shade. However, combined with other stand structure parameters, the study concluded that increasing basal area in western Oregon and stand density in eastern Oregon could result in higher shade on east-west flowing streams. The lower basal area requirements on small and medium streams were, therefore, predicted to provide less shade than on large streams, particularly if the trees had larger diameters and higher live crown ratios. Conversely, the study also highlighted the potential downfalls of managing strictly for shade. With shade as the primary goal, the riparian area would likely be managed towards the stem exclusion stage. The stem exclusion stage is likely to promote small diameter trees of poor vigor and, therefore, is unlikely to meet the other important functions of riparian areas.

> *Recommendation #8: Consider the findings from this study in concert with other ODF riparian monitoring results during the rule revision process currently underway.*
> The Board of Forestry is currently reviewing a report from the Forest Practices Advisory Committee on Salmon and Watersheds. The report is only applicable to western Oregon. The report proposes a "riparian package" with recommendations regarding adjustments to the basal area retention standards, no-cut buffer widths, and channel migration zone. The results of this study, while not compelling on their own, are supported by technical report #12. Specifically the Board of Forestry should consider changes to vegetation retention rules to increase the maintenance and promotion of shade on small and medium streams in western Oregon, while ensuring that other important riparian functions are retained.
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> A similar advisory committee process is currently underway in eastern Oregon. The results of this study will be used to inform that process on riparian stand conditions and stream shade in eastern Oregon.