Shade Conditions Over Forested Streams In the Blue Mountain and Coast Range Georegions of Oregon

ODF Technical Report #13

August 2001

Prepared by

Oregon Department of Forestry

Marganne Allen

and

Liz Dent

Acknowledgments

This study was a collaborative effort between the Oregon Department of Forestry's (ODF) Forest Practices Program and the Oregon Department of Environmental Quality. This study would not have been possible without the participation of private landowners, ODF forest practice foresters, and Forest Service staff from the Wallowa-Whitman, Malheur, and Siuslaw National Forests who identified and volunteered field sites. Jerry Clinton of ODF refined the field protocol, coordinated the project, and adapted the use of the hemispherical photography to field work in streams. ODF is grateful for the dependable field work and data collection by Kristin Cotugno, Cullen Bangs, Kyle Abraham, and the fire crews from the Grande Ronde, Wallowa, Prineville, and John Day field offices. Special gratitude goes to George Ice, Tim Lewis, Paul Ringold, Tom Rosetta, and Tamzen Stringham for the time and commitment they made to review the draft version of this paper. Recognition of the reviewers does not indicate their endorsement of the final report. The Oregon Department of Forestry and Oregon Department of Environmental Quality, through the federal 319 program, provided funds for this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Oregon Department of Environmental Quality (DEQ) sets water quality standards to protect beneficial uses. DEQ has identified stream temperature as one of the water quality standards that is not being met for streams in both eastern and western Oregon. Furthermore, the Oregon Plan identifies the need for action plans that will support recovery of water quality. In particular, the plan established a need to review load allocations, non-point source pollution, and effectiveness of current regulatory programs in achieving the recovery goals. This Best Management Practices (BMP) monitoring project supports both DEQ concerns and goals in the Oregon Plan by focusing on the relationship between riparian stand characteristics and shade because of its link with stream temperature.

This project was implemented in basins within the north coast and northeastern regions of Oregon (ODF Blue Mountain and Coast Range georegions). Data were collected in the Grande Ronde, John Day, Umatilla, Wallowa, Siletz, Tillamook, Nehalem, Lower Columbia, Necanicum, Clatskanie, and Alsea basins. Data were collected on both harvested stream reaches and those with no recent history of harvest. One goal of this project was to determine the range of shade levels provided over streams under varying forest management scenarios. A second goal was to investigate possible links between site and stand characteristics and shade.

BACKGROUND

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 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. This "general prescription," as well as three other prescriptions sampled in this study, is described below.

Table 1. Riparian Management Area widths.

Stream Size	Fish-bearing Stream (Type F)	Domestic Use (Type D)	Non-fish-bearing, Non-Domestic Use (Type N)
Small	50 Feet	20 Feet	--
Medium	70 Feet	50 Feet	50 Feet
Large	100 Feet	70 Feet	70 Feet

General Prescription (OAR 629-640-100): A standard conifer basal area target has been established that varies by stream size, type, and georegion. If the pre-harvest conifer basal area within the RMA exceeds the target, the landowner can harvest to the standard target while retaining a 20-foot, no-cut buffer, and a specified minimum number of trees per 1000 feet of stream length, which also varies by stream size. If the basal area is less than the standard target, but greater than one-half the standard target, the landowner can harvest the hardwoods outside of 20 feet. There were no RMAs in this study managed with the general prescription.

No-cut Buffer (OAR 629-635-310): The landowner can leave a fixed buffer width and not harvest within the RMA. There were 18 RMAs managed with a no-cut buffer in this study.

Alternative Prescription (OAR 629-640-300): If the basal area is less than one-half the standard target, the landowner can use an alternative prescription. There are two conditions which may warrant an alternative prescription: a catastrophic event or a riparian stand that is capable of supporting conifers, but which is currently dominated by hardwoods. Only the second condition was encountered in this study.

On sites that are hardwood-dominated, a riparian conifer restoration (RCR) prescription can be used to convert a hardwood-dominated riparian area to one dominated by conifers. Alternating conversion (maximum 500 feet long) and retention blocks (minimum 200 feet long) are established. In the conversion block, the landowner can harvest all trees to within 10 feet of the stream and must replant conifers. Within retention blocks, the landowner may apply general prescriptions if the block meets the basal area targets. If the retention blocks do not meet the standard target, then the landowner can harvest all conifers to within 50, 30, and 20 feet on large, medium, and small streams, respectively. There were two RMAs managed with RCR prescriptions in this study.

Site-Specific Plan (OAR 629-640- 400): A landowner has the option to develop a site-specific plan for harvesting within the RMA. The goal of this rule option is to encourage landowners to look for opportunities to enhance and restore riparian areas. There were 22 RMAs managed with a site-specific plan in this study.

It is assumed that the State Water Quality Standards (WQS) for stream temperature, developed by DEQ, will be met by adhering to BMPs, unless monitoring shows otherwise. The stream temperature parameter used in Oregon to index water quality is the seven-day moving mean of daily maximum stream temperature (seven-day maximum). Standards include numeric criteria (seven-day maximum equal to, or less than, 64°F for salmonid habitat, 55°F during spawning and rearing, and 50°F for bull trout). If numeric criteria are exceeded, then temperature conditions cannot be degraded (i.e. increased) by anthropogenic disturbance. The DEQ documented over 800 Oregon streams as water-quality limited on the 1998 303(d) list (DEQ 1995). Of the streams listed, over 700 were listed, in part, due to water temperature concerns.

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. Under this pilot study, shade, cover, and structural data were collected across a range of forest stand conditions to determine if the riparian stand conditions that result from harvesting can be directly linked to shade over the stream.

LITERATURE REVIEW

Many studies have documented increases in stream temperature due to timber harvesting. The degree of impact varies with harvest practices and stream characteristics. Historical practices, such as clearcut harvesting without leave-trees or riparian buffer strips, have been consistently shown to increase mean, maximum, and diurnal fluctuation of stream temperature (Levno and Rothacher 1967, Brown and Krygier 1970, Meehan 1970, Feller 1981, Hewlett and Fortson 1982, Johnson and Jones 2000). Current forest practices that maintain some level of riparian vegetation have been shown to be successful in minimizing or eliminating increases in stream temperature associated with harvesting (Brazier and Brown 1973, Kappel and DeWalle 1975, Lynch et al. 1985, Amaranthus et al. 1989). Riparian buffer width, while an important factor influencing stream temperature, needs to be considered in the context of the amount of shade provided by the riparian canopy (Brazier and Brown 1973). The importance of maintaining canopy to protect stream temperature lies in its ability to block incoming solar radiation and maintain a cool, humid microclimate. Other parameters which influence temperature include channel width, depth, stream flow, substrate, gradient, elevation, distance from divide, azimuth, ground water flux and temperature, cool-water tributary input, and air temperature (Brown 1970, Adams and Sullivan 1990, Sullivan et al. 1990, Caldwell et al. 1991).

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.

Measurement techniques can differ both in the parameter they measure (shade or cover) and their angle of view (wide, narrow, or point). Narrow-angle or point estimates of canopy *cover* can be measured with the moosehorn or by ocular estimates. Wide-angle estimates of cover can be obtained by angular canopy density (a type of densiometer), convex or concave densiometers, clinometers, or solar pathfinders. Hemispherical photography and solar pathfinder are tools that can be used to index *shade*.

There is some debate as to what is the most accurate method to assess shade or canopy cover. Using a moosehorn as the comparative method, Bunnell and Vales (1990) compared values of canopy cover as produced by a moosehorn, gimbal sight, densiometer, regular photographs, hemispherical photographs, and ocular point estimates in coniferous forests near Vancouver, British Columbia. Their findings are as follows (Figure 1). (1) As the height to base of live crown (HBLC) increased, canopy cover estimates increased. (2) Techniques with a wider angle of view produced higher estimates and less variable estimates of canopy cover. (3) As the canopy became more closed, the differences between canopy cover estimates decreased.

The moosehorn was originally developed as a means of field-truthing crown cover estimates from aerial photography (Robinson 1947). This tool provides a vertical, point-estimate of cover. Cook et al. (1995) compared a convex and concave densiometer to moosehorn measurements in northeast Oregon. Ranges in cover values from all the tools were similar, though both densiometers produced higher mean cover values. Both densiometers, relative to the moosehorn, had the least bias at extreme shade values (?10% and >70%) and the greatest bias between 10-30% cover.

Nuttle (1997) argues that it is not accurate to portray one method as being more correct than another, but rather that one must consider what process they are trying to represent beneath the canopy. An instrument measuring a wide angle of view may best represent processes such as snow dynamics and radiant energy flux. Crown cover and dominance might be better represented with vertical canopy measurements.

Hemispherical photography, a wide-angle view instrument, was used as early as 1924 to make observations of cloud conditions (Evans and Coombe 1959). Since that time, it has commonly been used to assess light conditions beneath canopies in studies of succession, competition, and undergrowth (Whitmore et al. 1993, Roxburgh and Kelly 1995, Clark et al. 1996). This technique facilitates photography of a hemispherical view of the sky (360? circular and 180? vertical) (oriented to south) by the use of a special fish-eye lens. Photographs are then developed, scanned into digital form, and analyzed using special software. The software analyzes each photograph and classifies grids, points, or pixels as either “open” (white) or “covered” (black). After the path of the sun is placed over the image, estimates of shade and radiation levels below the canopy are produced. Some of the assumptions and considerations of hemispherical photography are as follows (Roxburgh and Kelly 1995): (1) All and any leaves are assumed to completely block the passage of light. (2) Hemispherical photography cannot account for light transmission and reflection from leaves, or layers of leaves. Leaf orientation may also affect reflection and transmission. (3) During analysis, points on the photo are assessed as black (completely blocked) or white (clear sky). "Black" areas may actually have more light via transmission or reflection, while “white” areas may have more shade that do not appear due to glare. (4) The canopy is also assumed to be a single layer.

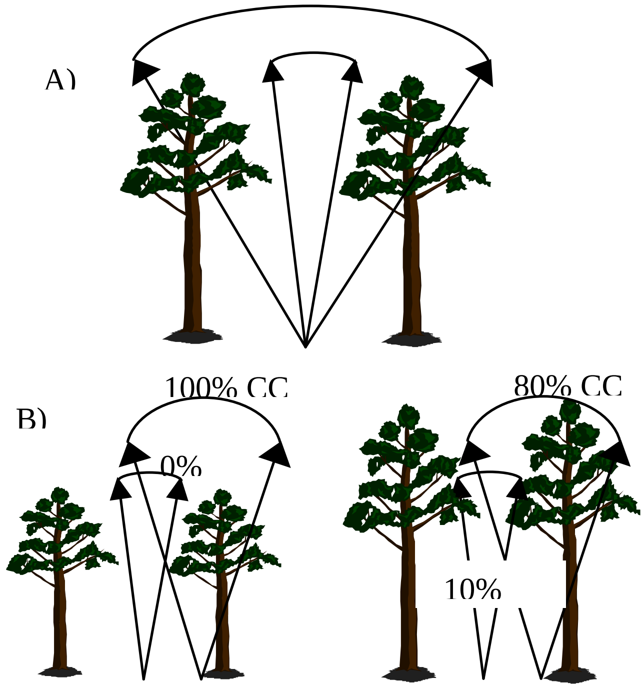


Figure 1. Angle of view and influence on canopy cover or shade measurements (adapted from Bunnel and Vales 1990). (A) Small angles produce large ranges in single point estimates. (B) Shorter heights to base of live crown produce large ranges in single point estimates.

Table 2 below summarizes both canopy cover and shade data from regions comparable to those investigated in this study. Some data from the Cascade Mountains are included. It is mostly comprised of cover data collected at the center of stream channels, though some upland and riparian data were included due to the scarcity of published stream shading and cover data. Some studies also do not specify what cover type the data were collected in (i.e. forest, agricultural). For streams adjacent to clearcut units in western Oregon and Washington, *cover* ranged from 17% in a 2- to 3-year-old clearcut with no stream buffer, to over 90% along streams with buffers ranging from 30-50 feet. Two old-growth stands shown (200 to 450+ years) had *cover* values of 75-82%. Channels without a recent history of disturbance had *cover* levels up to 89%. In 75- to 90-year-old stands in British Columbia, *shade* (not cover) values ranged from 75-90% in upland stands.

In northeast Oregon and the northern Rockies of Washington, *cover* values were lower overall (no shade data were available). Cover values ranged from 70-89% in upland stands without recent disturbance in northeast Oregon, while streams adjacent to partial cuts (32- to 72-foot buffers) ranged from 71-84%.

Table 2. Summary of canopy cover/shade research

Mean Cover (%)	Method	Zone	Stand Type	Stand Age (years or category)	Stream Buffer/Upslope Harvest	Locati
52,67,91,95	Densiometer	Stream	Douglas-fir	--	30-50 ft/Clearcut	Coast Range, WA
71,84	Densiometer	Stream	Douglas-fir	--	32-72 ft/Partial cut	N. Rockies, WA
80 78 78 59 65 79 56	Angular Canopy Density	Stream	--	--	100 ft/Clearcut 100 ft/Clearcut 30 ft/Clearcut 60 ft/Clearcut 60 ft/Clearcut 50 ft/Clearcut 8 ft/Clearcut	Coast Range, OR
17	Angular Canopy Density	Stream	--	2-3 yrs	--/Clearcut	Coast Range, OR
75	Angular Canopy Density	Stream	--	5-10 yrs	--/Clearcut	Coast Range, OR
87	Angular Canopy Density	Stream	--	15-22 yrs	--/Clearcut	Coast Range, OR
82	Angular Canopy Density	Stream	--	>200 yrs	NA	Coast Range, OR
85	Angular Canopy Density	Stream	Red alder	2[nd] growth	--/Clearcut (30-40 yrs post)	Cascade Range, OR
75	Angular Canopy Density	Stream	Douglas-fir, western hemlock	Old growth >450 yrs	NA	Cascade Range, OR
81[+] 82[+]	Clinometer	Stream	All cover types.	--	NA	Coast Range, OR:
89.1 89.3 89.4	Densiometer (overstory only – shrubs removed)	Riparian 5 m 10 m 15 m (dist. from stream)	Mostly alder-dominated stands, some conifer.	"lack of recent disturbance" est. 22-90+ yrs.	NA	Coast Range, OR
13.4 – 99.6 25.4 – 81.4 69.8 – 96.7 40.0 – 98.0 59.1 – 93.2 23.0 – 99.5	Densiometer	Stream	All cover types	NA	NA	Alsea vicinity, OR Siletz/Yaquina, OR Siuslaw vicinity, OI Lower Columbia, C Nehalem vicinity, C Wilson/Trask/Nestu

Mean Cover (%)	Method	Zone	Stand Type	Stand Age (years or category)	Stream Buffer/Upslope Harvest	Locati
70.1 29.3	Moosehorn	Upland	Grand fir – larch	Uneven: 50 years since last selective harvest	NA/Unharvested NA/Partial cut	Blue Mountains, OI
89.6 56.7 89.7 63.2	Densiometer	Upland	Grand fir – larch	Uneven: 50 years since last selective harvest	NA/Unharvested NA/Partial cut NA/Unharvested NA/Partial cut	Blue Mountains, OI
52, 66, 73	Moosehorn	Upland	W. hemlock/D.-fir, 7.3-25.6 m to base of live crown	75-90 yrs	NA/Unharvested	British Columbia, C
71, 79, 92	Densiometer	Upland	W. hemlock/D.-fir, 7.3-25.6 m to base of live crown	75-90 yrs	NA/Unharvested	British Columbia, C
82, 87, 90* (all as read from Fig. 2)	Hemispherical Photography (DSF)*	Upland	W. hemlock/D.-fir, 7.3-25.6 m to base of live crown	75-90 yrs	NA/Unharvested	British Columbia, C
75, 82, 84* (all as read from Fig. 2)	Hemispherical Photography (DFSF)*	Upland	W. hemlock/D.-fir, 7.3-25.6 m to base of live crown	75-90 yrs	NA/Unharvested	British Columbia, C

*Shade measurement (DSF – direct light factor, DFSF – diffuse light factor)
NA – Not applicable
-- No information provided
+ Medians

Cover and shade are influenced by a number of factors, including tree height. In an applicable study in Great Britain, Warren (1985) used hemispherical photography to correlate the presence of certain species of butterflies to shade levels in meadows. Not surprisingly, tree height was found to be a good predictor of shade levels in meadows (p-values and equations were not provided), with shade levels decreasing as the meadow width increased. Furthermore, the relationship between tree height and shade was different for those meadows with an east/west orientation rather than north/south.

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?

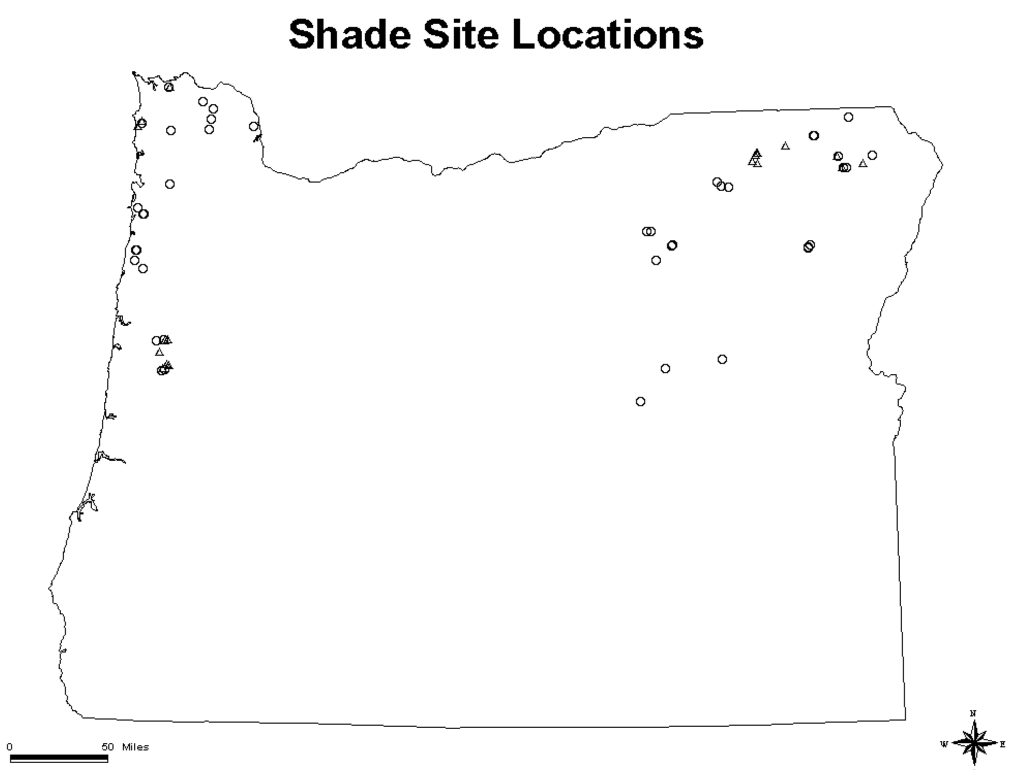
4. How do disturbances, other than harvesting, affect shade on forested streams?

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

STUDY DESIGN

STUDY AREA

This study was focused on the Blue Mountain and Coast Range geographic regions as described in the Oregon Department of Forestry forest practices rules (OAR 629-635-220) (Figure 2). Currently, temperature TMDLs have been completed for the Grande Ronde and Tualatin basins and in 2001, proposed TMDLs for temperature are in the Umatilla and Tillamook basins. Thirty-one sites in the Blue Mountain georegion and 30 sites in the Coast Range georegion were selected for a total of 61 sites, though cover and shade data were not collected at every site due to equipment problems.



○ Harvest Units

△ Unharvested—managed and unmanaged

Figure 2. 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.

GEOREGION DESCRIPTIONS

The information for the following georegion descriptions came from two main sources: The ODF rainfall map (www.odf.state.or.us/atlas/maps/rainfall.gif) and the EPA ecoregion map (USGS) and descriptions (CEC 1987).

The *Blue Mountain* georegion is characterized by low precipitation (ranges from 8 to 35 inches annually), most of which falls as snow. This georegion is distinguished from the neighboring Cascades and Northern Rockies georegions because the Blue Mountains are generally not as high and are considerably more open. Like the Cascades, but unlike the Northern Rockies, the region is mostly volcanic in origin. Only the few higher ranges, particularly the Wallowa and Elkhorn Mountains, consist of intrusive rocks that rise above the dissected lava surface of the region. Unlike the bulk of the Cascades and Northern Rockies, much of this ecoregion is grazed by cattle. Dominant tree species in riparian areas vary and include ponderosa pine, true firs, and larch with infrequent cottonwood, aspen, alder, and Engleman spruce.

The *Coast Range* georegion is characterized by high precipitation (70-200 inches annually), and dense overstory and understory vegetation. Riparian areas are typically dominated by an alder overstory and a salmonberry/sword fern understory. Riparian conifer species typically include western hemlock, western redcedar, and/or Sitka spruce. Douglas-fir is more prevalent farther away from the stream. The parent material is predominately Tyee sandstone and ocean basalts overlain with deep, well-drained soils. Steeper slopes in the mid- and south-coast areas result in extremely shallow soils.

SITE SELECTION

Sites were selected non-randomly in order to obtain a sample of harvested and unharvested sites with certain desired characteristics. ODF forest practices foresters (FPF) were asked to provide harvested stands with the following characteristics:

- Operations conducted after January 1, 1998.
- Harvest units with the same "prescription" on both sides of a stream.
- Harvest units involving large, medium, and small type F (fish-bearing) streams, and small type D (domestic water supply) streams.
- Stands with excessive blowdown (>75% of trees) were eliminated from the sample to avoid shade measurements with abundant downed wood as a confounding factor.

Unharvested stand data were collected at sites adjacent, or in close proximity, to harvested stands in order to sample shade conditions that may have existed prior to entry. In order to collect data on a wide range of unharvested stands, this sample includes both young, intensively managed areas, as well as older stands in the Umatilla, Wallowa-Whitman, Malheur, and Siuslaw National Forests. More specifically, Forest Service personnel were asked to provide a contiguous, unmanaged stand encompassing at least 700 feet of stream length (minimum 500-foot long plot with a 100-foot “buffer” at either end to reduce edge effects from adjacent stands). The stand had to extend at least 200 feet on either side of the stream (100-foot-wide plot with a 100-foot "buffer" at either end to reduce edge effects from adjacent stands).

SAMPLE SIZE

A total of 31 and 30 sites were monitored in the Blue Mountain georegion and Coast Range georegion, respectively. 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, both 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. Stand ages for unharvested stands averaged 65 and 90 years respectively in the Blue Mountain and Coast Range georegions. Stand ages for harvested stands averaged 68 and 65 years respectively in the Blue Mountain and Coast Range georegions. More information on stand age, site characteristics, and disturbance, other than harvesting, is discussed in the Results and Analysis section, and provided in Appendix A. Sample plots were established within each of these stands as described below.

PLOT DESIGN

At each site, a plot was established on both sides of the stream. The plot had a minimum length of 500 feet and a maximum length of 1000 feet, depending on the length of the harvest unit along the stream. Furthermore, plots were established a minimum of 100 feet from either the up- or downstream end of the harvest unit in order to minimize edge effects. The plot was 100 feet wide on each side of the stream measured from the average annual high water mark (Figure 3).

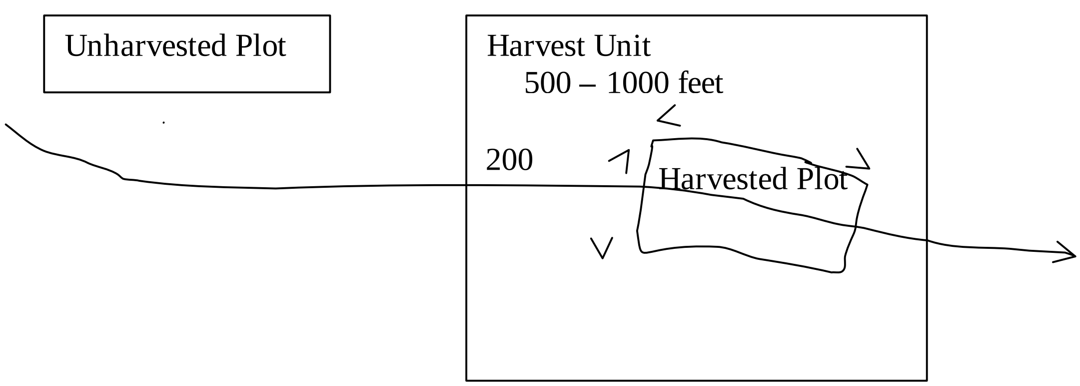


Figure 3. Schematic of plot location within harvest unit.

PARAMETERS AND FIELD METHODS

All trees ?6 inches diameter at breast height (DBH) 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 were measured every 200 feet. Shade and channel measurements were made every 100 feet. The specific parameters and field methods are described below.

Diameter at Breast Height. For every tree greater than six inches in diameter, the crew measured diameter at breast height using a logger's tape.

Tree Height. A laser range finder was used to measure total tree height on every fifth tree by species.

Live Crown Ratio (LCR). LCR were measured using a laser range finder on the same subset of trees where the tree height was taken. LCR is a ratio of the crown length to the total tree height. The crown length began at the first whorl of branches on a conifer and at the first live branch on a hardwood.

Overstory Age. Increment cores of dominant conifer and/or hardwood trees were taken for stand age estimation.

Distance to Stream. Distance from bankfull was measured for every tree using a range finder.

Tree Species. Species was documented for every tree that was measured.

Topographic and Forest Shade Angle. Topographic and forest shade was measured with a clinometer as the angle in degrees to the highest source of topographic and forest shade.

Topography. The site will be characterized by valley type. Slope was measured along transects every 200 feet through the plot.

Shade. Hemispherical photographs were taken every 100 feet at the center of the channel (Figure 4). Shade was calculated from the photos using Hemiview software. Shade values reported in this study are point estimates of one minus the Global Site Factor (1 - GSF) averaged along the stream length within a plot. The GSF is the proportion of both direct and diffuse energy under a plant canopy relative to the available direct and diffuse energy for the given site's latitude/longitude. The available energy is a constant provided in the Hemiview manual (Hemiview User Manual No. 2.0). The GSF calculated for this study was based on the sun's position on June 30.

Overstory vs. Shrub-Associated Shade. Photos with the fish-eye lens camera were taken at three feet above the water surface to capture both low shrubs and overstory, and at 10 feet above the water surface to minimize the influence of low shrubs and maximize overstory influences.

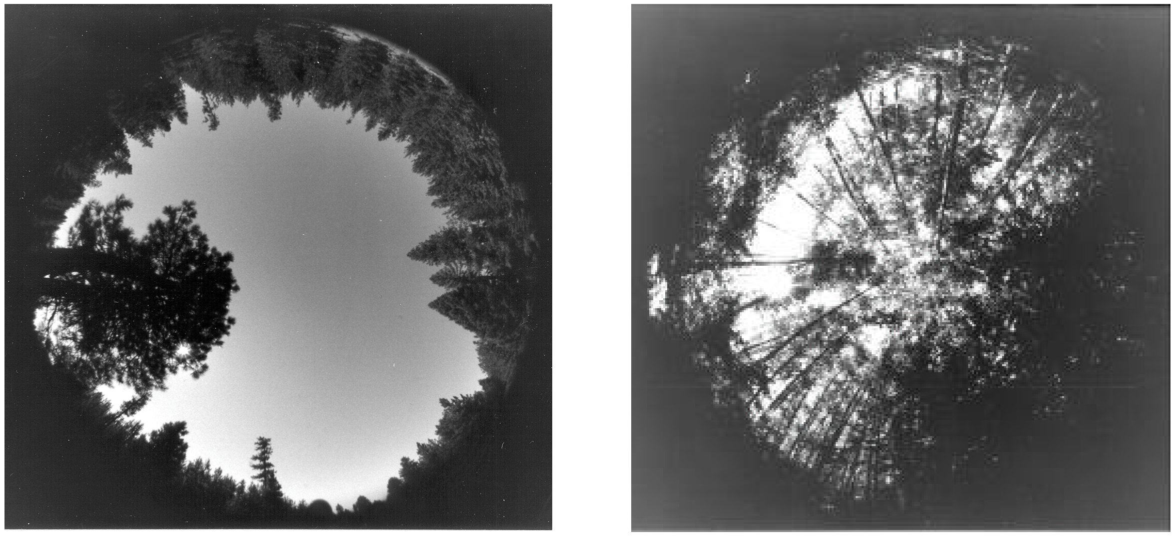


Figure 4. Examples of hemispherical (fish-eye) photographs taken at a site in the Blue Mountain georegion (left) and at a site in the Coast Range georegion (right).

Cover. Cover was measured with a densiometer every 100 feet at the center of the channel.

Streamflow. Streamflow was measured using a velocity meter as a function of cross-sectional channel area at the downstream end of the plot.

Azimuth. The azimuth (general valley direction) was measured with a compass.

Gradient. Channel and sideslope gradient were measured using a clinometer.

Thalweg Depth. Water depth in the main flow as measured with a surveyor's rod.

Wetted Width. The wetted width of the stream channel as measured with a logger's tape or surveyor's rod.

Bankfull Width. The channel width at the estimated average annual high water mark, measured with a logger's tape or surveyor's rod.

Substrate. The dominant channel substrate as classified into sizes shown in Table 3.

Floodprone Width. Measured every 200 feet following Rosgen (1994). Defined as the width at 2x the bankfull thalweg depth.

Table 3. Codes used for size classification of channel substrate.

Code	Material	Size Description
BD	Bedrock	Bigger than a car/continuous layer
BL	Boulders	Basketball to car-sized
CB	Cobble	Tennis ball to basketball
GR	Gravel	Ladybug to tennis ball
FN	Fines	Smaller than a ladybug

Channel incision. Channel incision was described as the ratio of the floodprone width to the bankfull width following Rosgen (1994). The floodprone area is defined as the width measured at an elevation determined at twice the maximum bankfull depth. Floodprone width will be measured with a hip chain or logger's tape.

Buffer width. Measured every 200 feet, from the highwater mark to the first cut tree.

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.

RESULTS AND DISCUSSION

SITE CHARACTERISTICS

STAND AGE

Harvested 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. In the Blue Mountains, the long history of selective harvest practices and more frequent fires makes estimates of stand age more difficult. However, 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. According to the core data, Blue Mountain harvested stands ranged in age from 26-123 years and averaged 68 years. Coast Range harvested stands ranged in age from 35-125 years and averaged 65 years.

Unharvested Sites. In the Blue Mountain georegion, unharvested stand 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.

SAMPLE DISTRIBUTION: STAND TYPE, MANAGEMENT, AND STREAM SIZE. Thirty-one sites were sampled in the Blue Mountains. A total of 30 sites were monitored in the Coast Range georegion, though shade or cover data were not collected at three sites due to equipment problems. 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. Both the harvested and unharvested samples were dominated by small and medium streams in both georegions (Table 4). 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.

Roughly half of the monitored sites in the Blue Mountain georegion were in stand conditions typical of large industrial ownership (14 of 31) with the remainder of sites split between small, private ownership (8 of 31) and federal ownership (9 of 31) (Table 4). Coast Range georegion sites were represented almost entirely by large industrial ownership (22 of 30) sites. Overall, 60% (11 sites) of the unharvested sites were on federal ownership and 40% (eight sites) were on industrial managed land.

There are two prescriptions to consider at harvested sites. The first deals with the management prescription applied to the RMA and the second deals with the management prescription applied to the adjacent upland area. See the Introduction and Background for a detailed description of RMA prescriptions. Of the harvested sites in both georegions, none of the RMAs were managed with a general prescription. In the Blue Mountains, two riparian areas were managed with a no-cut buffer, zero with riparian conifer restoration, and 19 with a site-specific plan. In the Coast Range georegion, 16 RMAs were managed with a no-cut buffer, two with a riparian conifer restoration, and three with a site-specific plan. The majority of the adjacent uplands in the Blue Mountain georegion were thinned (19 out of 21 sites) while all of the adjacent uplands in the Coast Range were clearcut to the buffer's edge (21 out of 21 sites). With the exception of two sites in the Blue Mountains, harvest occurred on both sides of the stream at all harvested sites. For detailed information about each site, see Appendix A.

Table 4. Number of sites in each stand type, ownership, prescription, and stream size.

SITE CHARACTERISTIC	GEOREGION	
	BLUE MOUNTAIN	COAST RANGE
Stand Type		
Harvested	21	21*
Unharvested	10	9^
Ownership		
Industrial	14	22
Non-industrial	8	2
Federal	9	6
Riparian Prescription		
Basal Area	0	0
No-Cut Buffer Width	2	16
Rip.Con. Restoration	0	2
Site Specific	19	3
Unharvested	10	9
Upland Prescription		
Clearcut	2	21
Thinned	19	0
Unharvested	10	9
Stream Size		
Small	14	14
Medium	13	10
Large	4	6

* Two sites are missing shade data.
^ One site is missing cover data.

DISTURBANCE OTHER THAN HARVESTING
In both georegions, and for harvested and unharvested stands, the majority of the sites were in narrow, steep or moderately steep, V-shaped valleys (Table 5). In the Blue Mountain georegion, substantial differences existed in disturbance and stand characteristics between harvested and unharvested sites. It is critical to understand that these inherent differences between harvested and unharvested stands create confounding results when trying to interpret cause and effect relationships between one of these factors and shade. In the Coast Range georegion, for harvested sites, the most commonly observed evidence of disturbance, other than harvesting, was blowdown. Other

disturbance and stand characteristics for the Coast Range georegion were similar for harvested and unharvested sites.

Table 5. 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.

In the Blue Mountain georegion, 76% of the sites were in steep, V-shaped valleys, while 100% of the unharvested sites were in steep, V-shaped valleys (Table 5). Aside from the percent of sites with insect and disease, disturbance mechanisms observed at harvested sites differed markedly from disturbance mechanisms observed at unharvested sites. The most commonly observed evidence of other disturbance for harvested sites was grazing (81%). Fire (24%), insect and disease (24%), and blowdown (14%) were less commonly observed. Conversely, the unharvested sites had minimal grazing activities (20%) and no recent evidence of fires (0%). Insect and disease was the most commonly observed disturbance mechanism on unharvested sites (20%) and was observed at similar levels as harvested sites. There was a marked difference between harvested and unharvested sites with regard to dominant overstory species. Harvested sites were almost evenly distributed among white fir (29%), Douglas-fir (33%), and pine (38%) stands. Conversely, none of the unharvested sites were in pine stands; the majority were white fir (80%) stands, with the remainder in Douglas-fir and Englemann spruce (20%) stands. It is critical to understand that these inherent differences between harvested and unharvested stands in the Blue Mountain georegion create confounding results when trying to interpret cause and effect relationships between one of these factors and shade.

In the Coast Range georegion, 79% of the harvested sites and 89% of the unharvested sites were in steep, V-shaped valleys. Aside from harvesting, the most commonly observed disturbance for harvested sites was blowdown (32%). No evidence of recent disturbance was observed on the unharvested sites. The percent of harvested sites dominated by conifer (26%), hardwood (69%) and mixed (5%) overstory stands was similar to the percent of unharvested sites dominated by conifer (33%), hardwood (56%), and mixed (11%) overstories.

BASAL AREA COMPARED TO FPA STANDARD BASAL AREA TARGETS

A landowner has multiple options for managing riparian areas (see Introduction and Background for a detailed discussion of management options in riparian areas). One scenario under which RMAs can be managed is if the pre-harvest basal area within the RMA exceeds the "standard target" for basal area. If there is basal area within the RMA at levels that exceed the standard target, a landowner has the option to harvest the "excess" basal area (referred to as a general prescription). However, all of the excess basal area cannot necessarily be harvested because of leave-tree requirements. The landowner must retain enough trees of the required diameter and species/1000 feet of stream to meet the standard target and tree count requirements. In addition, they may not harvest within 20 feet of the stream. There were **no** RMAs managed with a general prescription in this study (see Site Characteristics for a breakdown of riparian prescriptions). However, basal areas within study RMAs were compared to standard basal area targets in the FPA as means of evaluating if the monitored RMAs retained substantially more basal area than is required under the general prescription.

Basal area was calculated separately for the left and right sides of the stream so the number of RMAs is twice that of the original sample size. This was done because of variability between left and right riparian areas and, because under the FPA, each side must be treated individually in the harvest plan. It is important to note that it is not appropriate to use these data to assess compliance with forest practice rules. The standard target for basal area only applies to sites that are managed with a general prescription, which none of these were. For example, if a medium harvested site had less basal area than the standard target after harvesting, but was managed with a no-cut, 70-foot buffer, then the measure of compliance would be if a 70-foot, no-cut buffer was retained.

TOTAL BASAL AREA IN RMAS

A wide range of total basal area within RMAs was observed on both harvested and unharvested RMAs in both georegions. Highly variable RMA basal area was consistent across all stream sizes in both georegions, with the exception of small, unharvested RMAs in the Coast Range georegion (Figures 5A and B).

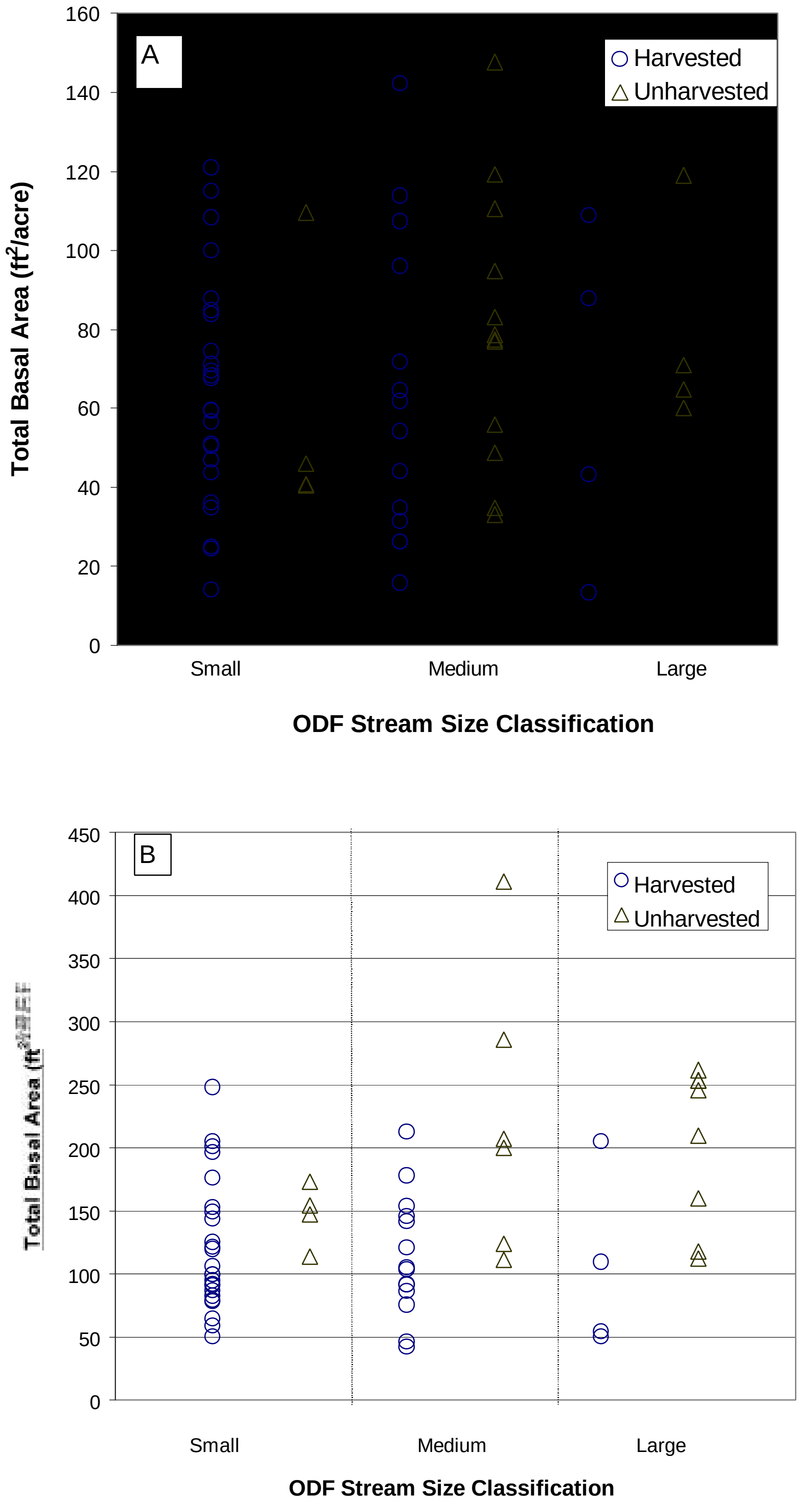


Figure 5. Total basal area (hardwoods and conifers) within RMAs on small, medium, and large streams in (A) Blue Mountain and (B) Coast Range georegions.

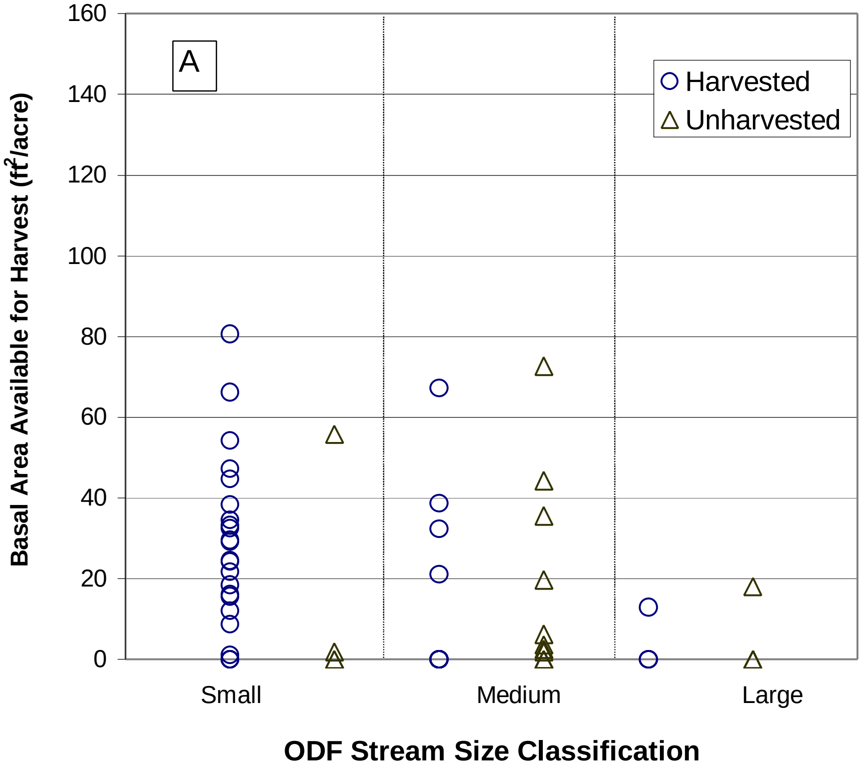
In the Blue Mountain georegion, basal areas ranged from 14-120, 16-142, and 13-109 sq.ft./acre for harvested small, medium, and large streams, respectively. In the Coast Range georegion, basal areas ranged from 50-249, 42-213, and 50-205 sq.ft./acre for harvested small, medium, and large streams, respectively. For unharvested RMAs in the Blue Mountain georegion, basal areas ranged from 41-110, 33-148, and 60-119 sq.ft./acre for small, medium, and large streams, respectively. For unharvested RMAs in the Coast Range georegion, the basal areas ranged from 114-173, 111-411, and from 112-261 sq.ft./acre for small, medium, and large streams, respectively.

Basal Area Available for Harvest

The standard basal area targets vary by georegion, stream size, and adjacent upland harvest prescription (clearcut versus thinning). In the Blue Mountain georegion, for thinning operations adjacent to streams, the standard targets are 44, 75, and 96 sq.ft./acre for small, medium, and large streams, respectively. In the Coast Range georegion, for clearcut harvesting adjacent to streams, the standard targets are 35, 75, and 100 sq.ft./acre for small, medium, and large streams, respectively. Trees must meet diameter and species criteria to count towards the standard basal area target (FPA-applicable basal area). Thus FPA-applicable basal area is commonly less than the total basal area within the RMA. This is particularly significant in the Coast Range georegion where most hardwood basal area is not applicable to the standard target. In the Blue Mountain georegion, an average of 99% and 95% of the total RMA basal area could contribute to the standard target on harvested and unharvested RMAs, respectively, with little variation between stream sizes. On average, in harvested RMAs along Coast Range streams, 50%, 55%, and 19% of the total RMA basal area was applicable to the standard target on small, medium, and large streams, respectively. On average, in unharvested RMAs along Coast Range streams, 41%, 73%, and 45% of the total RMA basal area was applicable to the standard target on small, medium, and large streams, respectively.

In addition to species and diameter requirements, FPA-applicable basal area within 20 feet of the stream is typically not available for harvest. In general, the “harvestable” basal area retained on harvested RMAs exceeded the requirements on small streams, was mixed on medium streams, and was insignificant on large streams in both georegions.

In the Blue Mountain georegion, the average percent of the total basal area retained, yet available for harvest, was 33%, 10%, and 3% on small, medium, and large harvested streams, respectively. For unharvested RMAs, the average percent of total basal area available for harvest was 14%, 13%, and 4% on small, medium, and large streams, respectively (Table 6). On harvested RMAs, the range of total basal area available for harvest decreased as stream size increased. The basal area available for harvest was similar on small and medium streams, but varied from 0-81 sq.ft./acre. Large streams had 0-13 sq.ft./acre available for harvest (Figure 6B).



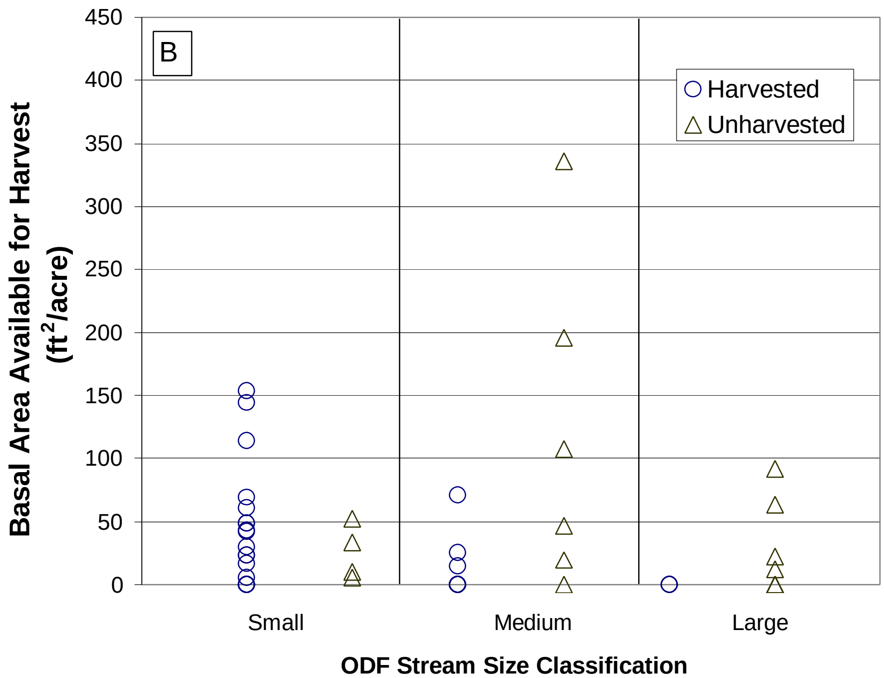


Figure 6. Basal area available for harvest under current FPA for RMAs on small, medium, and large streams in (A) Blue Mountain and (B) Coast Range georegions.

Table 6. Percent of total basal area available for harvest.

Geo-region	Stand Type	Percent of Total RMA Basal Area Available for Harvest		
		Small Average (range)	Medium Average (range)	Large Average (range)
Blue Mountain	Harvested	33% (0-67%)	10% (0-47%)	3% (0-12%)
	Unharvested	14% (0-51%)	13% (0-49%)	4% (0-15%)
Coast Range	Harvested	22% (0-72%)	4% (0-40%)	0% (0-0%)
	Unharvested	17% (4-35%)	41% (0-82%)	15% (0-48%)

In the Coast Range georegion, the average percent of the total basal area that was retained, yet available for harvest, was 22%, 4%, and 0% on small, medium, and large harvested streams, respectively. For unharvested RMAs, the average percent of total basal area available for harvest was 17%, 41%, and 15% for small, medium, and large streams, respectively (Table 6). The total basal area available for harvest varied greatly between streams and decreased as stream size increased on harvested RMAs. In harvested RMAs, available basal area ranged from 0-153 sq.ft./acre on small streams and 0-71 sq.ft./acre on medium streams. None of the harvested RMAs on large streams were eligible for additional harvest (Figure 6A).

The high variability in basal area within riparian areas has been observed in 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 indicates that, on average, basal area retained on these study sites was in excess of what can result from a basal area prescription on small streams. Retained basal area on medium and large streams did not substantially exceed requirements on these study sites. However, 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 the Coast Range georegion.

While these sites do not test the application of the basal area prescription, data from an ODF Compliance Monitoring Study (ODF personal communication, Joshua Robben) suggest the retention levels on these shade study sites were actually lower than what is commonly retained under the standard basal area prescription. For the compliance study, a random sample of 189 sites throughout the state yielded 188 RMAs. Preliminary results indicate that it was common for landowners to both utilize a no-cut buffer width prescription, and to exceed rule requirements when applying the basal area prescription. Specifically, ODF compliance monitoring indicates that 58.4% of stream length was managed with no-cut buffers, 34.9 % with standard target, and 6.7% with site-specific or other plans. FPA-applicable basal area retained on standard target prescriptions exceeded the standard target on average by 230%, 162%, and 122% on small, medium, and large streams, respectively. FPA-applicable basal area retained on these shade study sites exceeded the standard target on average by 35% and 89% on small streams in the Blue Mountain and Coast Range georegions, respectively, and by 2% on medium streams in the Blue Mountain georegion. However, for the shade study sites, average FPA-applicable basal area retained was insufficient on medium and large streams to meet standard targets.

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?

RANGE IN SHADE CONDITIONS

Shade values reported in this paper are reach averages, based on an analysis of individual 3ft. photos taken every 100 feet (see Parameters and Field Methods section of this paper). Shade in the Blue Mountain georegion ranged from 28-83% and 63-84% over harvested and unharvested streams, respectively. Shade in the Coast Range georegion ranged from 51-89% and from 72-95% over harvested and unharvested streams, respectively (Figure 7 and Table 7). In the Blue Mountain and Coast Range georegions, 10% and 35% of sites, respectively, had greater than 80% shade (Figure 8). In the Blue Mountain and Coast Range georegions, 65% and 92% of the sites had greater than 60% shade, respectively. In the Blue Mountains, 35% of the sites had 20-60% shade, while in the Coast Range georegion, 7% of the sites had 40-60% shade. In both georegions, sites with less than 60% shade were comprised entirely of harvested sites. As the shade category increased, the proportion of unharvested sites relative to harvested sites increased (Figure 8).

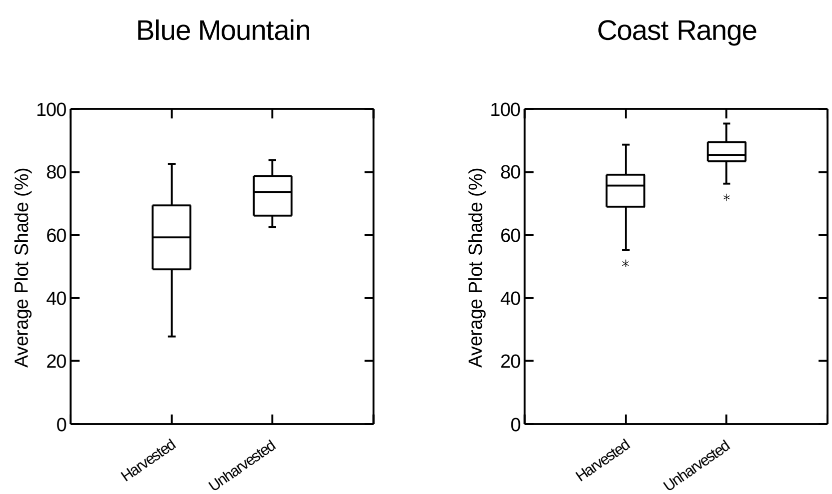


Figure 7. Stream shade under harvested and unharvested RMAs by georegion.

Table 7. Summary statistics for cover and shade by georegion and stand type. SD = standard deviation is based on average plot values.

Georegion	Stand Type	Cover				Shade (3-foot height)			
		Avg. (%)	Measures (#)	n^	SD	Avg (%)	Measures (#)	n	SD
Blue Mtns.	Harvested	65	148	21	20.9	58	148	21	15.4
Blue Mtns.	Unharvested	81	75	10	14.4	73	74	10	7.9
Blue Mtns.	Total	70	223	31	20.0	62	222	31	19.5
Coast Range	Harvested	92	140	21	8.6	73	128	*19	9.9
Coast Range	Unharvested	98	73	*8	2.8	84	73	9	7.5
Coast Range	Total	94	213	30	8.4	77	201	28	13.8

* In the Coast Range georegion, hemispherical photos (shade) were not taken at two sites and densiometer measures (cover) were not taken at one site due to equipment problems.
^ n = sample size

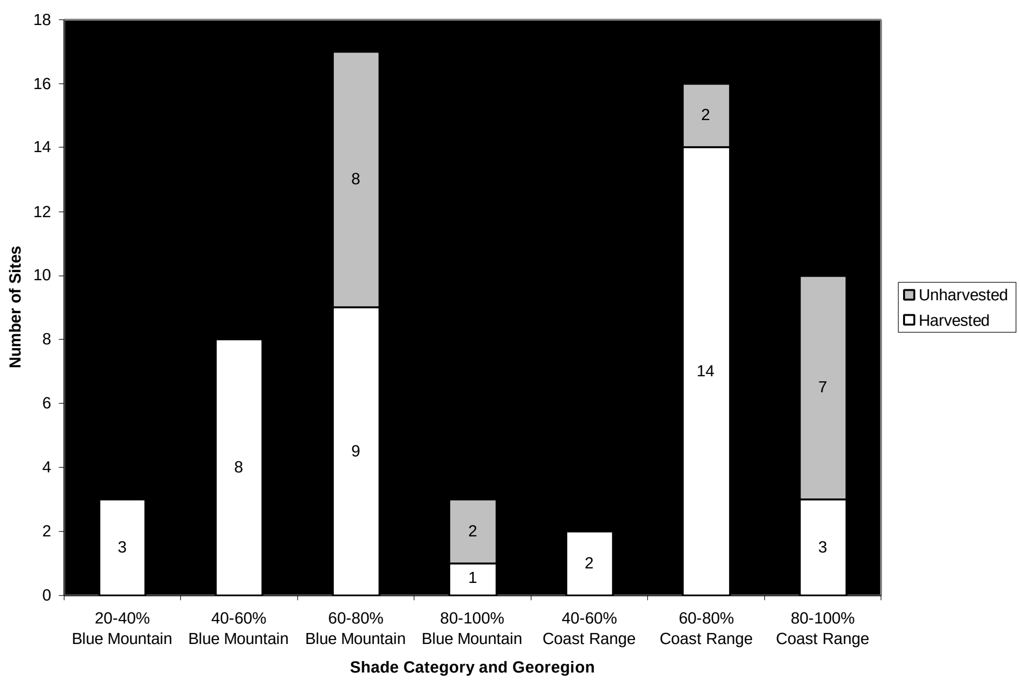


Figure 8. Distribution of harvested and unharvested sites among shade classes by georegion.

In general, shade was lower on large streams than on small and medium streams. For unharvested streams, shade was lower on large streams than on small and medium streams by an average of 5% and 9% in the Blue Mountain and Coast Range georegions, respectively. However, the small sample size and wide range in shade on large streams limits the explanatory power of stream size on shade (Table 8 and Figure 9). There was considerable overlap between shade values over small and medium size streams for both harvested and unharvested streams in both georegions. Two extreme points are displayed in the box plots (Figure 9) for the harvested Blue Mountain and Coast Range streams. While the low shade value in the Coast Range may be explained by blowdown, there is no readily apparent reason for the extreme point in the Blue Mountains. Neither point was considered for removal as an outliner.

Table 8. Shade and bankfull widths of harvested and unharvested sites in the Blue Mountain and Coast Range georegions.

Blue Mountain Stand Type	Shade and Bankfull Width by ODF Stream Size											
	Small (n)			Medium (n)			Large (n)			Total (n)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
<u>Harvested</u>	12			7			2			21		
Shade (%)	40	60	80	29	55	69	28	55	83	28	58	83
Bnkfl. Width (ft)	6	14	21	17	24	32	23	32	41	6	19	41
<u>Unharvested</u>	2			6			4			12		
Shade (%)	63	73	84	63	74	83	72	80	88	63	73	88
Bnkfl. Width (ft)	10	12	15	20	26	36	21	29	37	10	25	37

Coast Range Stand Type	Shade and Bankfull Width by ODF Stream Size											
	Small (n)			Medium (n)			Large (n)			Total (n)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
<u>Harvested</u>	12			6			1			19		
Shade (%)	51	72	83	61	77	89	NA	55	NA	51	73	89
Bnkfl. Width (ft)	5	10	17	17	20	27		32		5	14	32
<u>Unharvested</u>	2			3			2			7		
Shade (%)	83	89	95	85	89	93	66	69	72	66	85	95
Bnkfl. Width (ft)	6	7	8	7	19	26	30	33	37	6	14	37

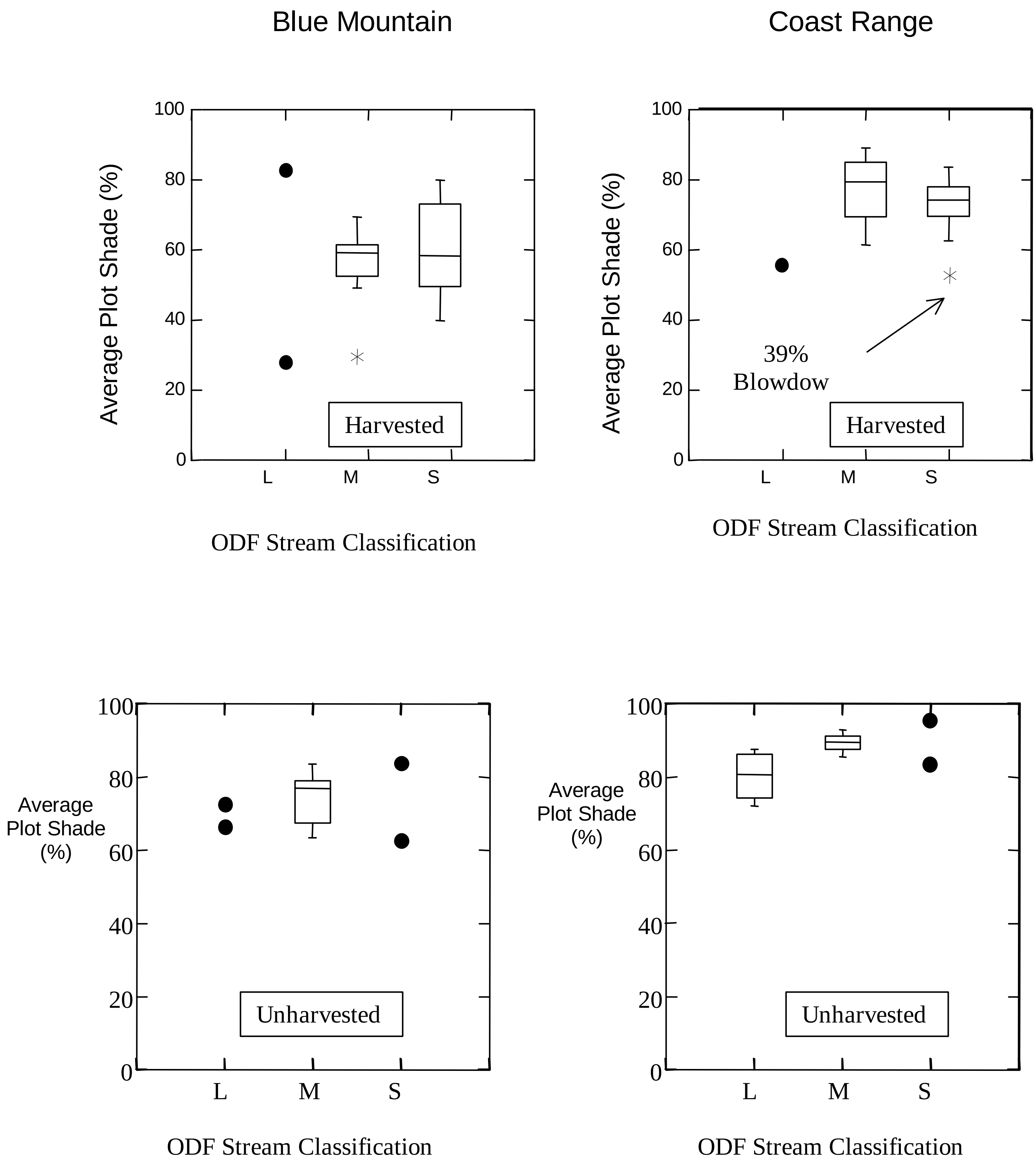


Figure 9. Range in shade by ODF stream class, for harvested and unharvested streams in each georegion. LF = large, M = medium F, S = small.

HARVESTED/UNHARVESTED COMPARISONS

Average stream shade in harvested stands was 15% and 11% less than unharvested stands in the Blue Mountain and Coast Range georegions, respectively (Figure 7). 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.

The variability of shade conditions in harvested stands was also greater than that of unharvested stands (Table 7). The variability in shade and cover (standard deviation = 20.0 and 19.5, respectively) was higher in the Blue Mountain georegion than in the Coast Range georegion (standard deviation = 8.4 and 13.8, respectively). For individual plots, the standard deviations for shade ranged from 2.3-20.0 in the Blue Mountains and from 2.3-16.8 in the Coast Range (Appendix B).

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

Detailed descriptions of the three prescriptions represented by these data are provided in the “Introduction” section of this paper. The most commonly used prescription in Blue Mountain harvested RMAs was a site-specific plan (90%) followed by a no-cut buffer (10%). In the Coast Range georegion, the no-cut buffer prescription was most common (74%), while the Riparian Conifer Restoration (RCR) and site-specific prescriptions constituted 10 and 16% of harvested RMAs, respectively.

All RMA prescriptions demonstrated lower average shade than unharvested stands (Figure 10). In the Blue Mountains, the greatest average difference between RMA prescriptions and unharvested RMAs occurred where a site-specific (SS) prescription was used (-16%). Generalizations can not be made about the SS prescription in the Blue Mountains as it resulted in a wide range of shade conditions, half of which occur within the range of unharvested stand conditions. The SS prescription can be used to tailor harvest within the RMA to very specific silvicultural goals. For example, a landowner may thin and replant insect and disease pockets in a poorly stocked RMA using this prescription. The no-cut buffer prescription averaged 11% less shade than unharvested RMAs.

The three RMA prescriptions sampled in the Coast Range georegion differed little in means and range of shade. The two RCR harvest units had the greatest average difference in comparison to unharvested stands in the Coast Range georegion (-13%), followed by no-cut buffer width prescriptions (-12%) and SS prescriptions (-10%). Shade produced by the SS and RCR prescriptions had a wide range of values and sample sizes were small.

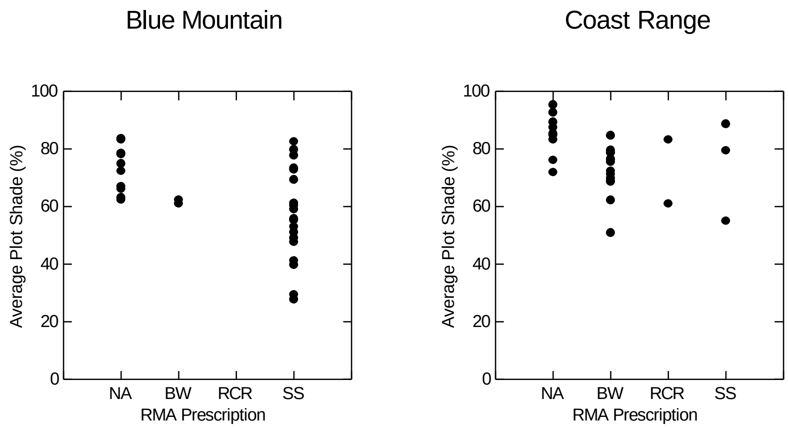


Figure 10. Scatterplot of shade by RMA prescription and georegion. NA = Not applicable, for unharvested sites, BW = No-Cut Buffer Width, RCR = Riparian Conifer Restoration, SS = Site-Specific Plan.

Buffer width is another factor that may aid in explaining the variability in shade conditions that results from different RMA prescriptions (Figure 11). Buffer width was measured as the distance from bankfull to the first cut tree, at 200-foot increments, on transects perpendicular to the channel. In this study, if the distance from bankfull to the first cut tree was greater than 100 feet, the distance was noted as "100+". The average buffer width values in these cases are low estimates. For example, a site-specific RMA with buffer widths of 55, 75, 82, 100, and 100+ feet, would be calculated to average 82 feet though it would exceed that by some amount. Buffer width distances exceeding 100 feet occurred only with the site-specific prescription, and are noted in Figure 11 as "SS+".

In the Coast Range georegion, there was a slight positive association of average shade with buffer width, but no such pattern was exhibited in the Blue Mountains. Overall, buffer width did not provide any further explanation for observed variation in stream shade on harvested reaches.

Overall, the RMA prescription and buffer width retained did not explain observed variation in stream shade on harvested stands.

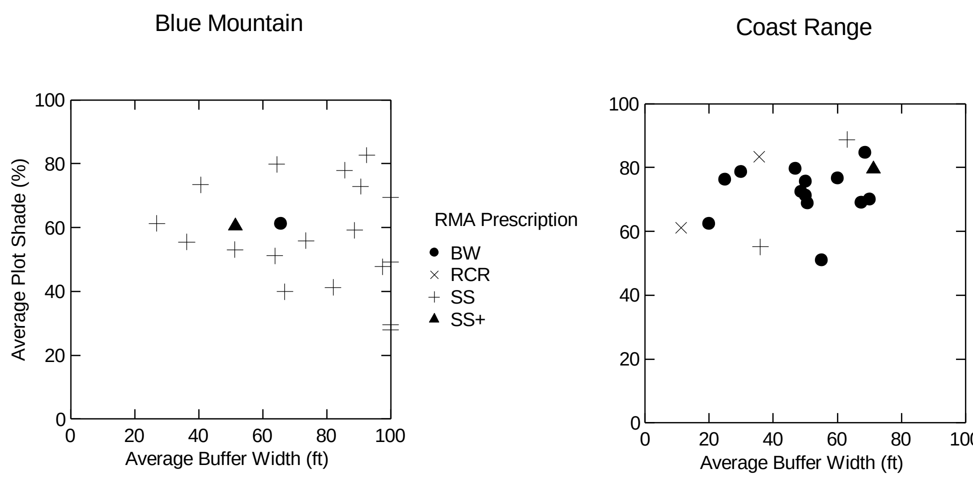


Figure 11. Average Plot Shade by average buffer width and RMA prescription for each georegion. SS = Site-Specific Prescription, SS+ = average buffer widths contain values that exceed 100 feet, BW = No-Cut Buffer, RCR = Riparian Conifer Restoration. Note: Only 38 sites had buffer width data.

Comparison of Shade Results to Other Literature

Data collected in similar regions and vegetative cover types (forested, harvested, or unharvested) as those in this study were summarized in the Literature Review section. The data from the literature, as well as the ODF shade and cover data from this study, can be compared to determine how the range in shade as defined by these data align with observations from other studies. Before discussing the comparisons, however, it is helpful to evaluate the relationship between shade and cover.

The densiometer is commonly used in field studies as a surrogate or index of shade. In general, the densiometer is less expensive and provides a more rapid assessment of stream cover than hemispherical photography. However, not all cover actually casts a shadow on the stream surface. Cover measures were compared to shade measures to determine the accuracy with which cover approximates shade provided to the stream surface. While cover proved to be a reasonable predictor ($r2 = .76$) of shade, the densiometer tended to over-predict shade, especially at higher cover levels (>70%) (Figure 12). Average cover measurements were 11% higher than shade measures (P-value < .01). Cover for all sites averaged 80%, while shade for all sites averaged 69%. Densiometer measures had greater variance and standard deviation than shade measures (Appendix D). The remainder of this paper utilizes shade as calculated from the 3ft. Hemiview photos unless otherwise stated.

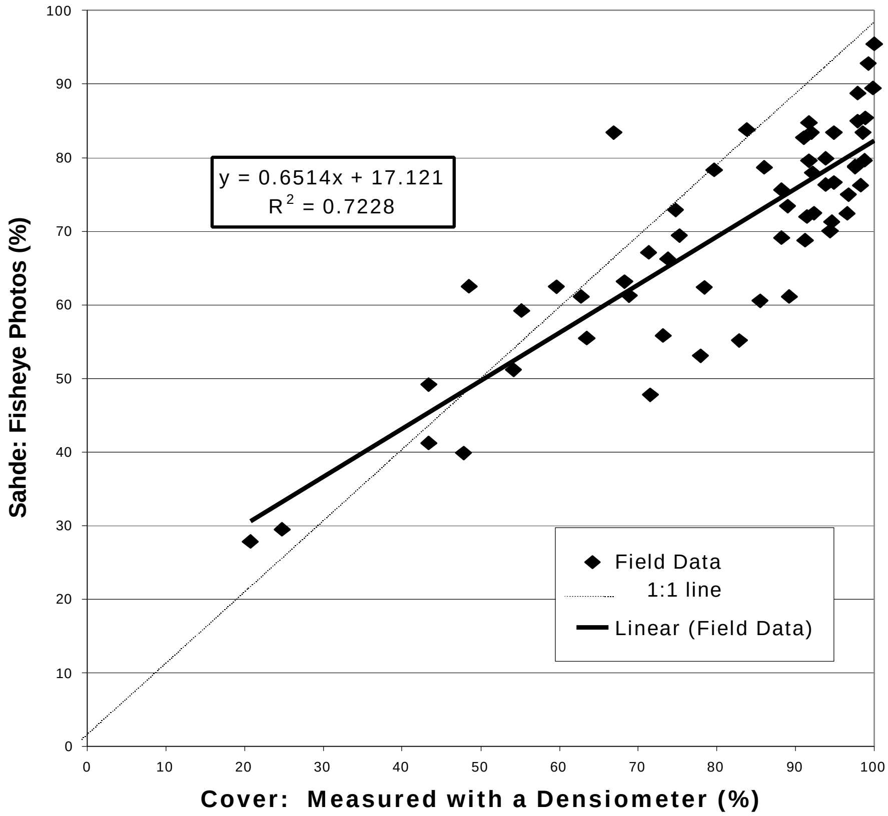


Figure 12. Relationship between shade and cover measurements.

The data from the literature, as well as the ODF shade and cover data from this study, are graphed together in Figures 13 and 14. ODF cover data are similar to other studies in eastern sites (northeast Oregon and northern Washington Rockies intermountain sites), though minimum ODF cover values tended to be lower (Figure 13). ODF cover was comparable to ODF shade values at the eastern sites. Considering the characteristics of the linear regression between shade and cover in the previous section, this is not surprising. The eastern shade values are in the range where the densiometer predicts quite well, while in the well-vegetated western sites, the densiometer tended to over-predict shade.

For the western sites (western Oregon and Washington), ODF shade data are comparable to shade and cover values found in other studies (Figure 14). The ODF cover data, however, were consistently higher than both the ODF shade and shade/cover values from other studies. One reason for this may be due to differences in the methods used to measure cover. Almost half of the cover data from older stands in western sites from other studies utilize angular canopy density, which angles the densiometer to face the angle of the sun, or the moosehorn, a narrow-angle measurement. If only densiometer data were included in the cover data from other studies, the average cover value would be

85%, as opposed to 78% for all cover values. The average ODF cover value for unharvested western sites is 98% (Table 2 of the Literature Review section).

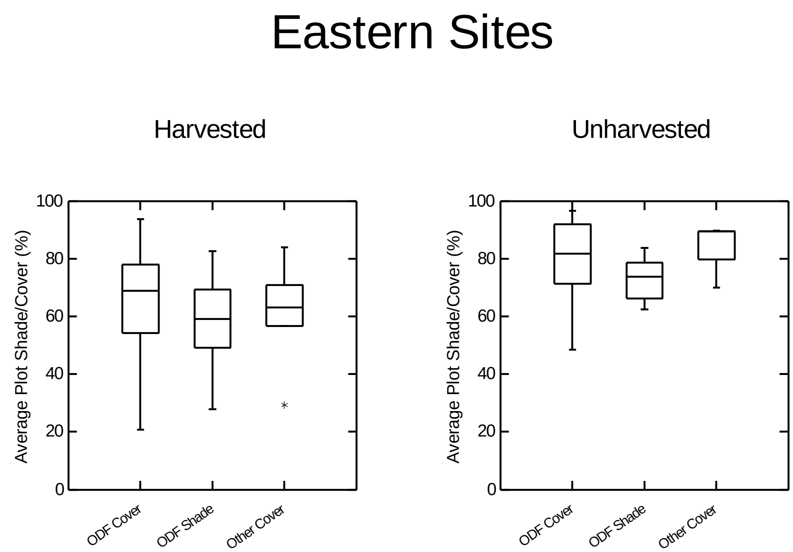


Figure 13. Comparison of ODF cover and shade data to literature from other eastern (intermountain) sites.

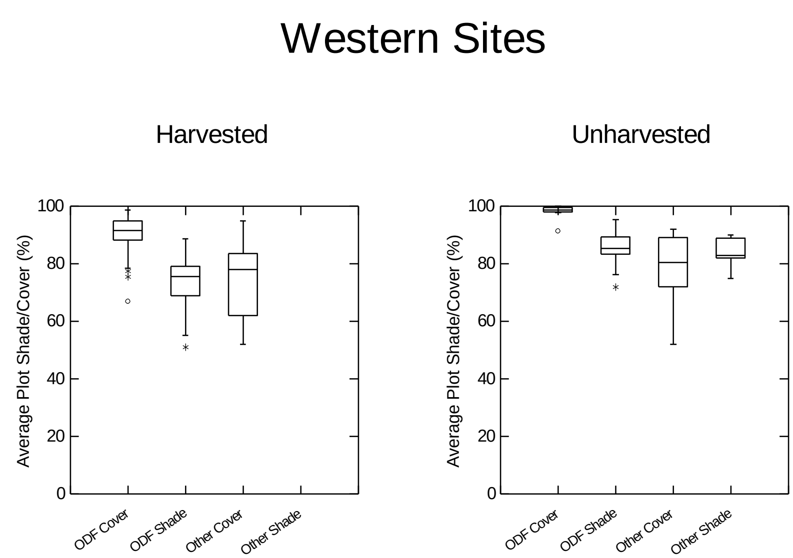


Figure 14. Comparison of ODF cover and shade data to literature from other western sites.

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

Stream channel and valley morphology data were collected to appraise their influence on shade over streams. Table 9 summarizes the average and range in channel parameters observed in this study and the sample size for each. An examination of relationships between each of the parameters and shade was conducted.

Table 9. Summary of channel characteristics by georegion.

CHANNEL PARAMETER	**Blue Mountains**	**Coast Range**
Bankfull Width (ft) Avg. (Min-Max)	21 (6 - 41)	16 (5 - 37)
Floodprone Width (ft) Avg. (Min-Max)	48 (7 - 104)	32 (12 -102)
Incision Ratio* Avg. (Min-Max)	2.4 (1.4 - 6.6)	2.2 (1.1 - 4.7)
CHANNEL GRADIENT (%) AVG. (MIN-MAX)	5.3% (1.2 - 11.7%)	7.9% (1.3 - 29.8%)
Aspect (# of sites)		
East/West	11	12
North/South	20	16
Valley Type (# of sites)		
Broad, Constraining Terraces	0	0
Narrow, Filled V-Shaped	0	0
Broad, Multiple Terraces	0	0
Narrow, Moderate V-Shaped	16	20
Narrow, Open V-Shaped	4	4
Narrow, Steep V-Shaped	10	4
Broad, Wide-Active Floodplain	1	0

*Unitless ratio of floodprone to bankfull width. Values <1.5 are considered incised.

Overall, there were no strong relationships between shade and floodprone width or gradient. General trends of increasing average shade with decreasing stream size, decreasing bankfull width, increasing incision ratio, 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. Kruksal-Wallis non-parametric tests were performed to test statistical significance of the observed relationships among shade and channel and valley parameters. All statistical tests revealed no significant relationships with the exception of aspect ($p = .021$). A discussion on aspect follows. Graphical displays of all other channel and valley data are provided in Appendix C.

ASPECT

Radial graphs show distribution of sites by shade values in relationship to general stream channel orientation (Figure 15). Shade values are displayed in 10% increments beginning with 0% at center, 20% at the innermost ring, to 100% at the outer ring. Orientation of each graph is to true north (360?), and is depicted with lines radiating from center, outward, and are labeled with azimuths in degrees.

There is some indication in the Blue Mountains that north/south flowing streams had higher average shade. This was in contrast to lower shade over east/west flowing streams. Coast Range streams, of all aspects, usually exceeded 60% shade, with no obvious patterns associated with aspect. Average shade over east/west-flowing streams was 10% lower than on north/south flowing streams (Figure 16) in both georegions. Shade ranges, however, were quite broad and had nearly identical high and low values. The influence of aspect on observed shade is more fully explored in concert with stand structure in later sections of this paper.

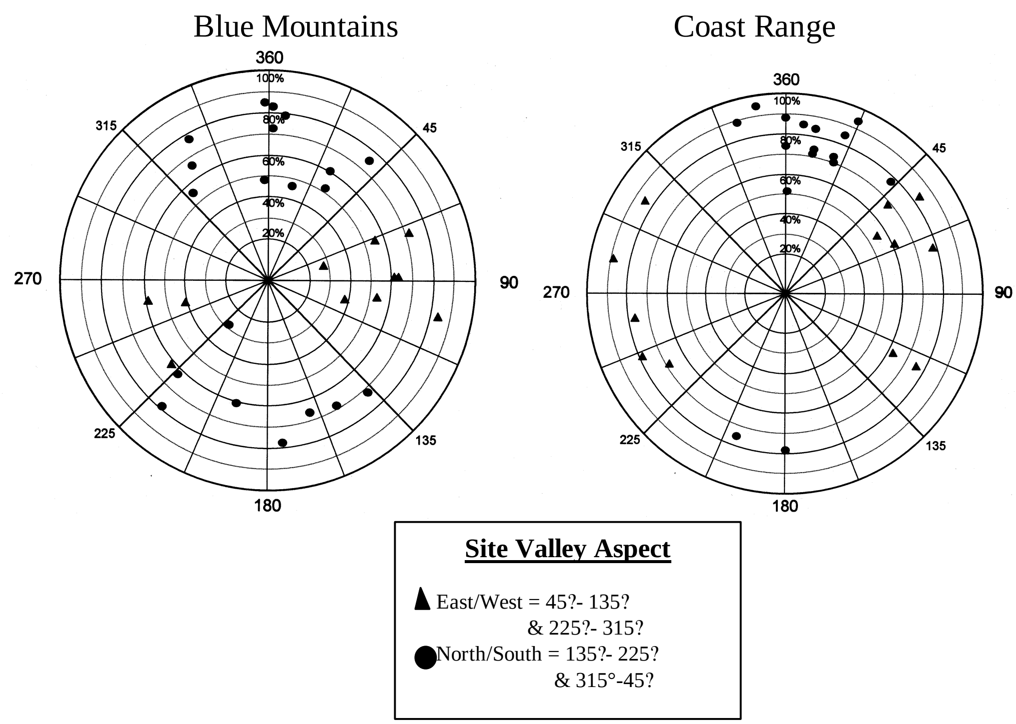
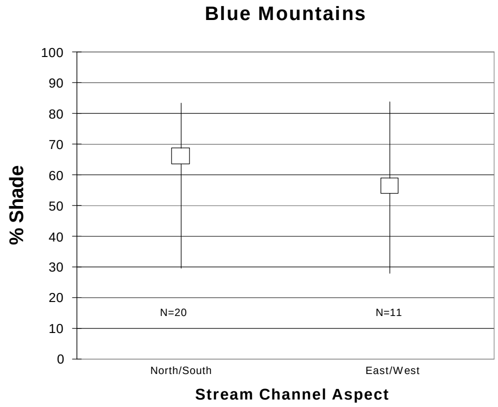
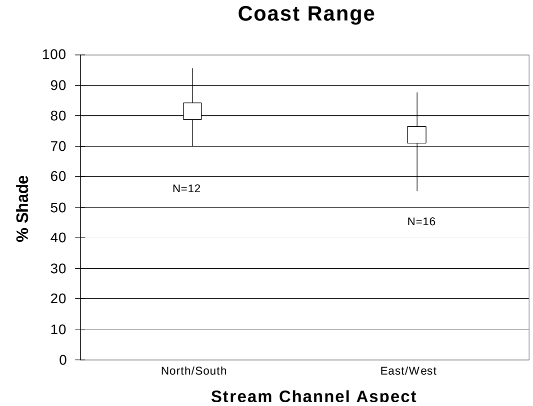


Figure 15. Radial plot of stream valley aspect by georegion.



Stream Valley Aspect



Stream Valley Aspect

Figure 16. Box and whisker plots of stream shade by stream valley aspect and georegion.

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

A number of disturbance mechanisms, human-caused or otherwise, can affect shade conditions over streams. These mechanisms can include, but are not limited to, forest harvest activities, grazing, forest stand insect and disease mortality or reduced vigor, fire, and blowdown. Included below is a discussion of how different disturbance mechanisms may be affecting average shade, after accounting for forest harvest activities.

BLOWDOWN

Percent of blowdown was calculated as a fraction of the total stems. These data suggest that substantial blowdown is a disturbance process that occurs predominantly in harvested stands. In harvested stands, the number of blowdown stems ranged from 0-47% in the Blue Mountains and from 0-39% in the Coast Range georegion (Figure 17). Whether or not a site was harvested appears to explain shade in the Blue Mountains more fully than the percent of blowdown. The same was true in the Coast Range, except the site with the greatest blowdown (39%) did exhibit markedly lower shade than all other harvested sites. Due to the biased sample (intentionally eliminated sites with more than 75% blowdown), it is inappropriate to fully explore blowdown and shade with these data. However, blowdown is likely a substantial factor for decreasing shade when almost half the stems in a stand are involved.

INSECTS AND DISEASE

Up to 27% of trees in an RMA were influenced by insects or disease in the Blue Mountains, while the maximum percentage of affected trees in the Coast Range did not exceed 5% (Figure 18). Though this disturbance mechanism was present in both harvested and unharvested stands, it does not appear to strongly influence stream shading.

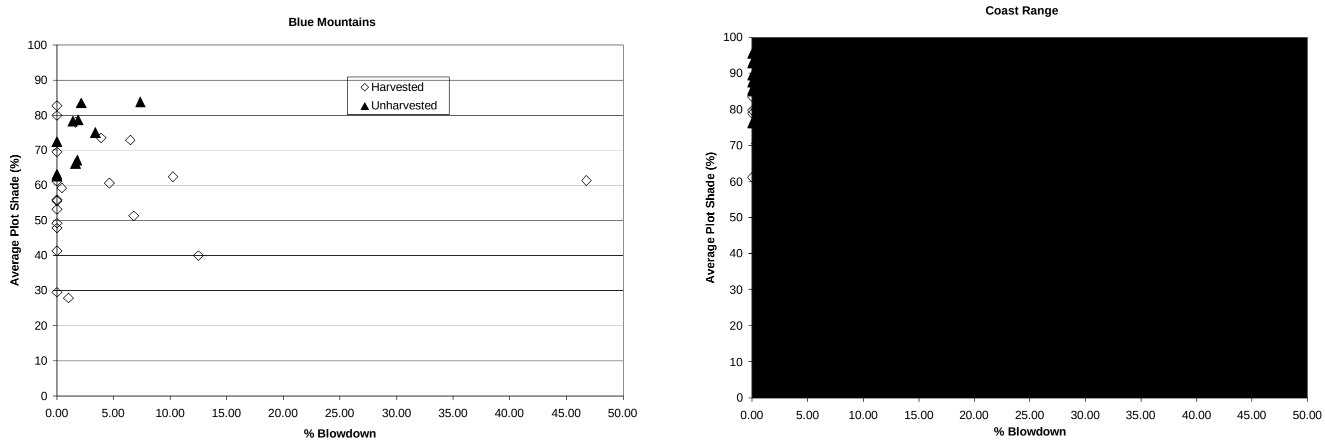


Figure 17. Average shade in relation to the percent of blowdown by georegion.

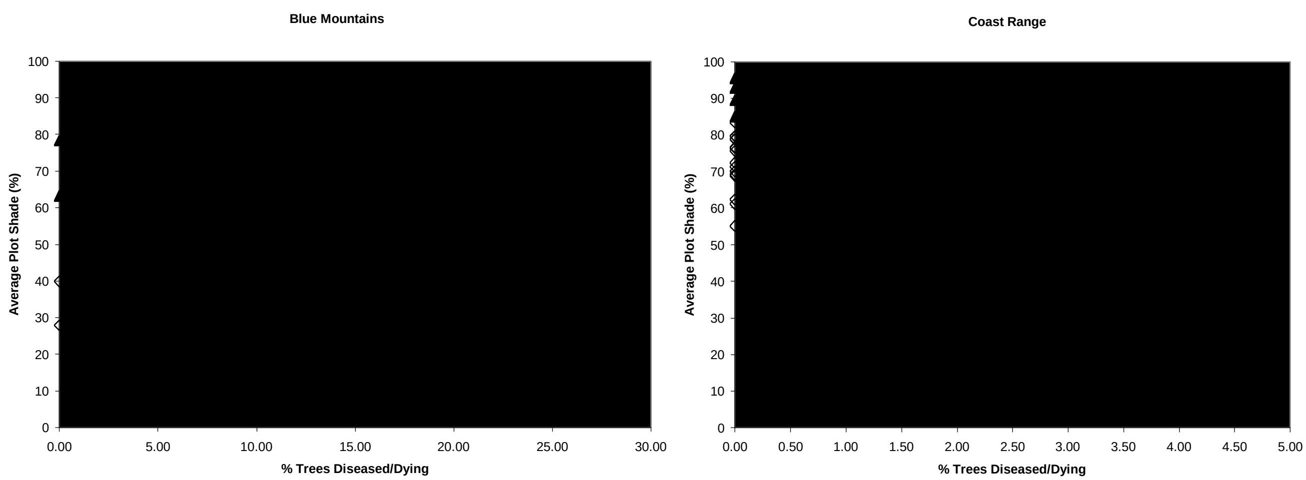


Figure 18. Shade in relation to the percent of diseased or dying trees by georegion.

FIRE

A site was identified as being affected by fire only if there was recent, obvious evidence that a fire had occurred there. Thus, this is only a snapshot of the short-term impacts of fire and not how long-term exclusion (or inclusion) of fire has affected stream shading. The expected very short-term impacts of fire would be a reduction in shade, though the re-growth of shrubs may well increase shading from previous levels in short order (depending on fire intensity). The only available comparison from these data is between harvested stands with and without fire impacts (Figure 19). These data do not suggest recent fire was highly influential on average shade at these sites.

GRAZING

Field personnel designated a plot as "grazed" if there was obvious evidence that cattle were present (animals visible, fresh droppings). Like forest harvest, a yes/no designation for grazing is an oversimplification of a potentially complex management practice. The season of grazing, number of animals, type of animals, dispersal, fencing, development of alternate water sources, and site conditions are some of the factors that can influence how grazing will affect stream shade. For the purposes of this study, however, the desire was not to test grazing practices as much as to account for it in addition to other factors. In both harvested and unharvested streams, the average shade was lower in grazed sites (Figure 20). Along harvested streams, the average shade level for grazed sites (n=17) was 16% lower than ungrazed sites (n=4) (55% vs. 71%). Along unharvested streams, the average shade level for grazed sites (n=2) was 12% lower than ungrazed sites (n=8) (63% vs 75%). Shade was 5% and 8% lower on grazed and ungrazed harvested sites, respectively, than grazed and ungrazed unharvested sites. While this indicates the importance of accounting for the multiple uses that occur in the Blue Mountains, both the limited sample size and potentially confounding factors, such as the dominant overstory vegetation, have not been adequately investigated

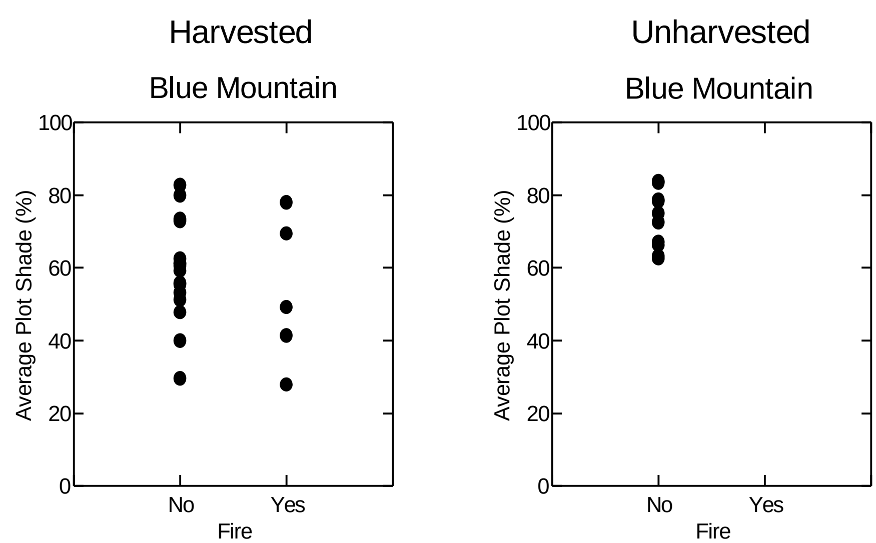


Figure 19. Fire and shade levels in harvested and unharvested Blue Mountain stands.

.

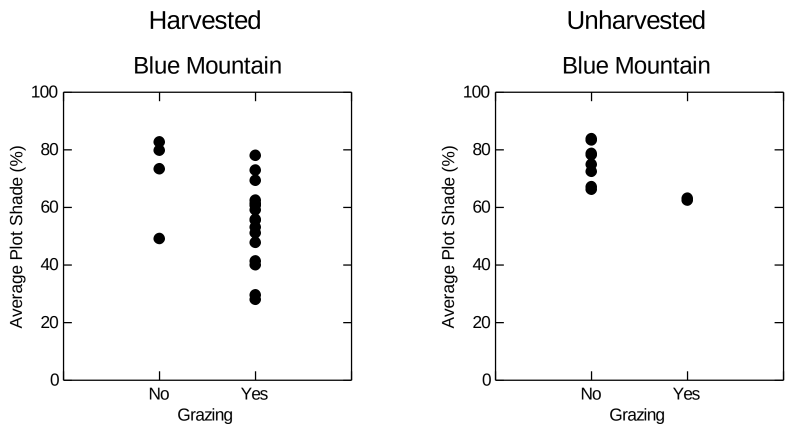


Figure 20. Grazing and shade in harvested and unharvested Blue Mountain stands.

WHAT ARE THE RELATIONSHIPS BETWEEN RIPARIAN STAND CHARACTERISTICS AND SHADE?

Dominant Overstory Vegetation

In both georegions, there was substantial overlap between shade levels produced by different dominant overstory vegetation types (Figure 21). For a display of the average shade by stand species composition, see Appendix D. Pine-dominated stands in the Blue Mountains had lower shade values overall (53%) than other types of coniferous stands, though there was a considerable range of shade conditions (28-80%) for pine stands. Unharvested stands were not represented in the pine category. Average shade conditions in unharvested white fir, hardwood, and conifer overstory types were 11%, 11%, and 20% higher, respectively, than harvested stands in the same vegetation type. Recent harvest entry did not produce distinct shade values in Douglas-fir/Englemann spruce stands (62% vs. 65%).

In the Coast Range, harvested conifer stands had lower average shade conditions than hardwood stands, though the two vegetation types were similar at the harvested sites. In mixed stands, harvested and unharvested sites had the same shade value (74%).

Greater representation of unharvested pine and Douglas-fir/Englemann spruce stands are necessary to further address overstory vegetation differences, as well as more data in mixed stands. In general, unharvested conifer, hardwood and white fir stands had the consistently highest shade conditions.

In the preceding section, different disturbance mechanisms were considered for their potential to explain variation in observed shade. Grazing seemed to have the most potential for being correlated with shade, though confounding factors, such as the dominant overstory vegetation, needed to be considered. From Figure 22, it is apparent that ungrazed sites are dominated by unharvested white fir stands which tended to have higher shade overall, and most grazed sites are in harvested stands, which tend to have lower shade. The lack of samples in unharvested pine stands is also problematic. To more fully account for grazing, this factor should be well represented with, and without, harvest and across overstory types.

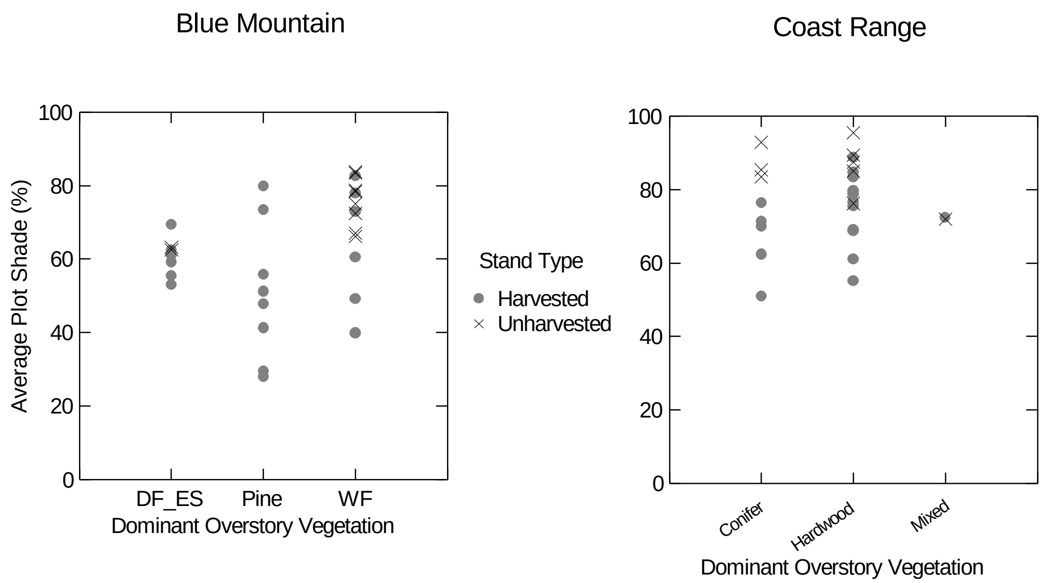


Figure 21. Dominant overstory, shade, and harvest designation by georegion. DF_ES = Douglas-fir/Englemann spruce, WF = White fir.

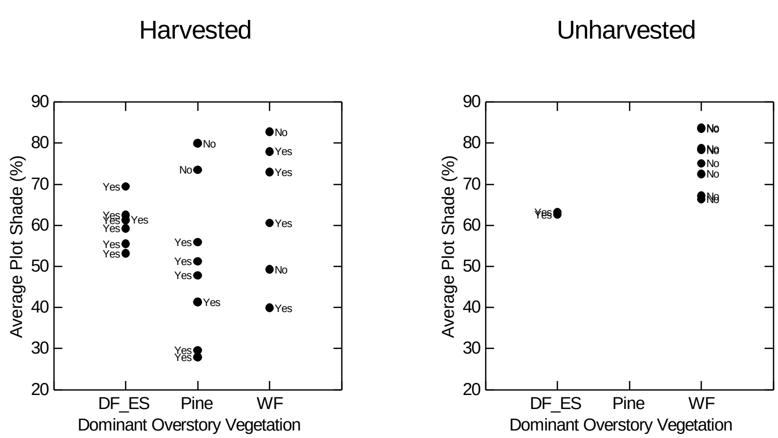


Figure 22. Grazing, shade, and dominant overstory type in the Blue Mountains.

UNDERSTORY VEGETATION

Hemispherical photographs (photos) were taken at heights of three (3ft.) and ten feet (10ft.) above the water surface in order to assess the influence of understory vegetation on stream shade. Since the 10ft. photos rarely eliminated understory shrubs from the photograph, the difference between the 3ft. and 10ft. photos generally underestimates the contribution that shrubs provide to stream shade. In addition, the 3ft. photos did not capture shade from low-growing grasses and forbes less than 3 feet tall. Therefore, the difference between shade at 3ft. and at 10ft. was interpreted as an approximation of shrub contribution to stream shade. The average difference between shade values for 3ft. and 10ft. photos ranged from 2.5% to 9.1% percent (Table 10).

Table 10. Differences between three- and ten-foot height shade measurements.

Georegion	Stand Type	Difference between 3- and 10-Foot Photo Shade Values (%)		
		Average	Maximum	Minimum
Blue Mtns.	Harvested	7.0	15.7	0.00
Blue Mtns.	Unharvested	5.9	10.0	1.8
Coast Range	Harvested	9.1	29.5	-1.0
Coast Range	Unharvested	2.5	7.7	-0.6

In the Blue Mountain georegion, on average, shrubs at harvested and unharvested sites provided at least 7.0% and 5.9%, respectively, of the shade at the stream surface. In the Coast Range georegion, at least 9.1% and 2.5% of the shade at the stream surface was provided by shrubs for harvested and unharvested sites, respectively. The maximum percent of shade provided by shrub cover (at least 29.5%) was observed at a Coast Range harvested site.

The approximate percent of shade provided by shrub cover was greater at harvested sites than unharvested sites in both georegions. There was no distinct trend between percent of shade contribution from shrubs and bankfull width, with both high and low shrub shade associated with narrow channels in both georegions (Figure 23). Shrub contribution to shade was less than 8% on channels wider than 25 feet in both georegions.

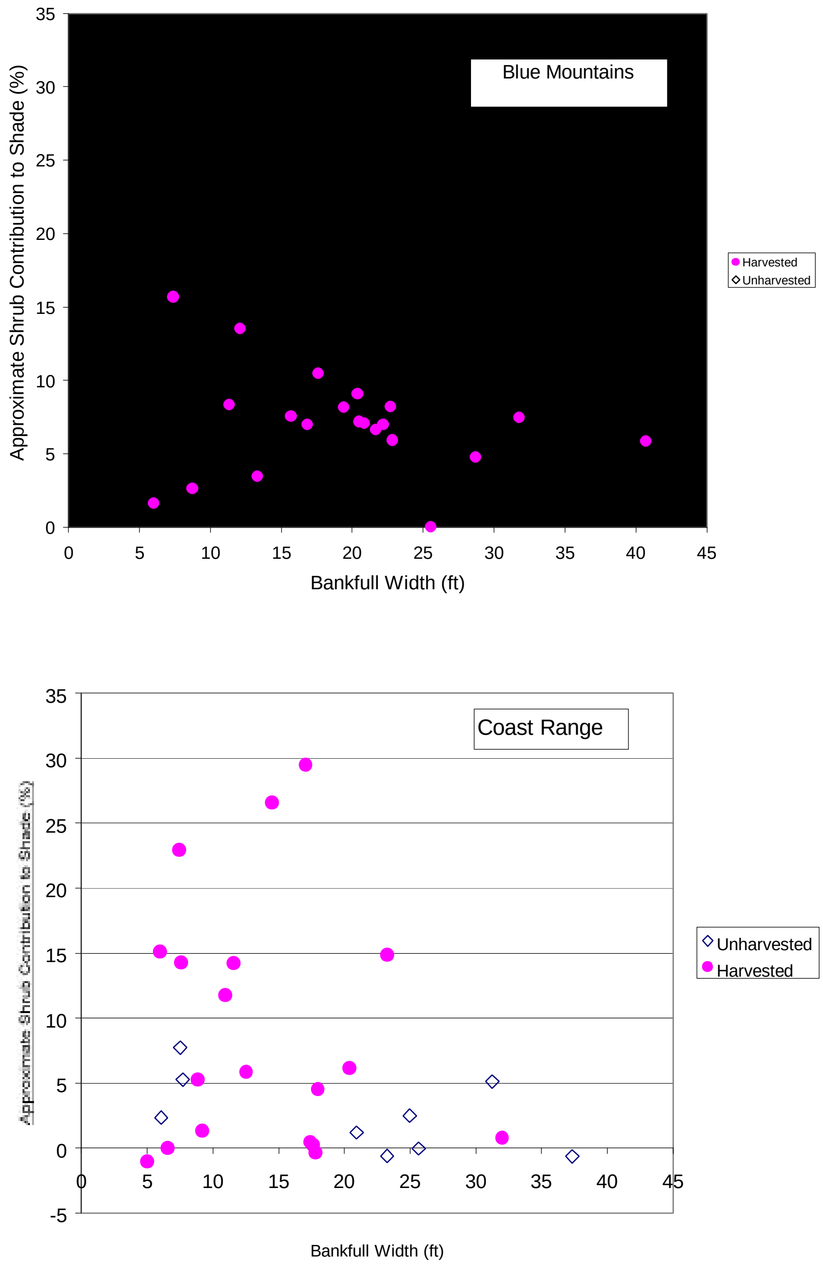


Figure 23. Approximate contribution by shrubs >10 ft tall to shade (3ft. – 10ft. photos) versus bankfull width for the Blue Mountain and Coast Range georegions.

BASAL AREA

A number of characteristics for the entire riparian stand (both sides combined) were plotted individually against shade in order to determine if a simple linear or curvilinear relationship existed (Appendix E). In both georegions, unharvested stands tended to have greater average shade, live crown ratios, tree heights, basal area, and trees per acre. Any given shade value, however, was produced by a range of stand conditions. For example, approximately 50 sq.ft./ac. of basal area in the Blue Mountains were associated with shade ranging from 29-80%. Similarly, approximately 80% shade was observed in Blue Mountain stands ranging from 27-45 trees/acre. Though there is a general association between higher stocking, taller trees, greater live crown ratios, and high shade, a simple and accurate predictive tool between a single stand characteristic and shade was not observed.

Cumulative basal area/acre was graphed versus distance from stream to evaluate the influence on shade of basal area from trees that are farther away from the stream. Shade categories were created and the cumulative basal area was averaged for sites within each category at incremental distances from bankfull (Figures 24 and 25). The shade categories were low (20-40%), fair (40-60%), moderate (60-80%), and high (80-100%). Scatterplots of individual sites grouped by shade category are provided in Appendix E and show a wide range of variability in each category. This is also demonstrated by the error bars (one standard error from the mean) in Figures 24 and 25.

In both georegions, there was a trend of higher shade with greater basal area. Differences in basal area between shade categories became more pronounced as the distance from bankfull increased. Observationally, there were no differences between basal area for sites with fair to moderate shade.

Blue Mountains sites with low shade (20-40%, n=3) were consistently associated with lower cumulative basal area at all distances from the stream. Sites with high shade (80-100%, n=3) had more basal area at distances greater than 60 feet from the stream. Sites with low shade averaged 71 sq.ft./acre at 100 feet from the stream. Sites with fair to moderate shade averaged 120 sq.ft./acre, and high shade sites averaged 189 sq.ft./acre.

In the Coast Range, there were no differences between basal area of sites with fair (40-60%, n=2) to moderate (60-80%, n=16) shade. However, at approximately 80 feet from the stream, sites with high (80-100%, n=10) shade had consistently higher basal area than those with fair to moderate shade. At 100 feet from bankfull, Coast Range sites with fair shade averaged 207 sq.ft./acre, while those sites with high shade averaged 303 sq.ft./acre.

Due to the observational nature of the data, concerns about outliers and non-constant variances, the Kruskall-Wallis test was used to investigate differences between basal area at the different shade categories (Table 11). This test cannot identify differences between specific groups, but does indicate if one or more of the groups is different.

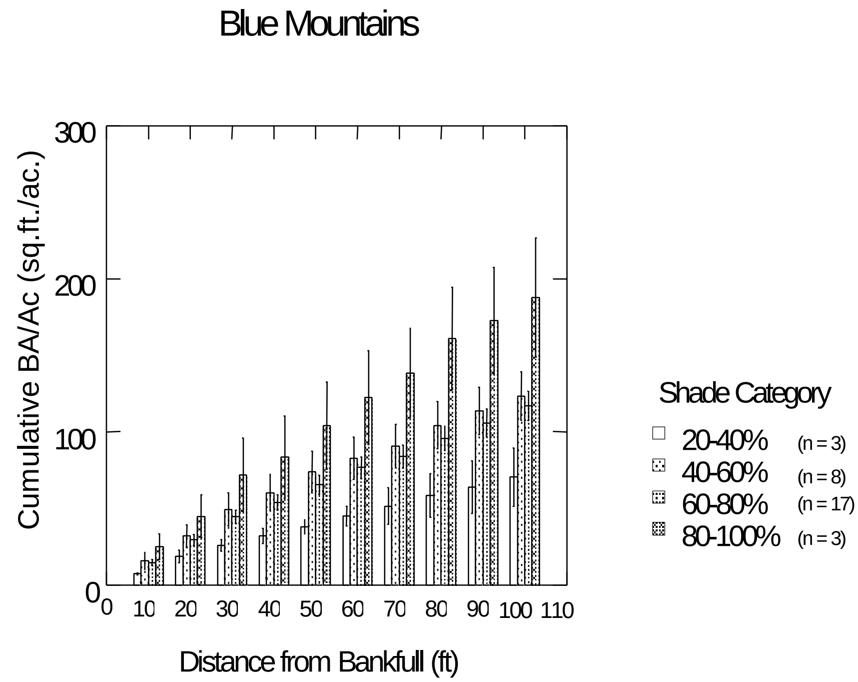


Figure 24. Mean cumulative basal area per acre by distance from bankfull and shade category in the Blue Mountains. Error bars show one standard error of the mean.

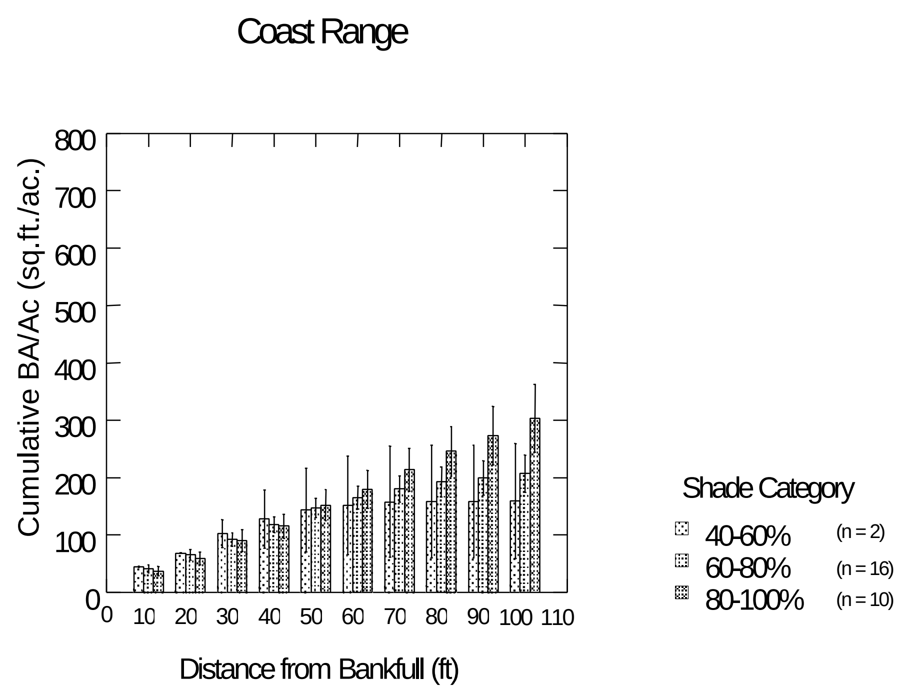


Figure 25. Mean cumulative basal area per acre by distance from bankfull and shade category in the Coast Range. Error bars show one standard error of the mean.

In the Blue Mountains, there was evidence of a difference in basal area between shade categories (p=0.000). This difference began at 40 feet from bankfull where the low and high shade categories began to separate (p=0.076). The difference in group basal areas becomes more suggestive at 60-80 feet where the error bars of low (20-40%), moderate (40-80%), and high (80-100%) shade categories cease to overlap (p=0.051 and 0.040).

There was no indication of a difference in basal area between shade categories in the Coast Range (p=0.560). When tested at specific bankfull distances (20, 40, 60, 80, and 100 feet), there was still no detectable difference in basal area between shade categories (p=0.98).

Table 11. Kruskall-Wallis test for differences in cumulative basal area or trees per acre between shade categories for all data or at specific distances from bankfull.

Distance from Bankfull	Blue Mountains (p-values) (df = 3)	Coast Range (p-values) (df = 2)
	Cumulative (ft2/acre)	Cumulative (ft2./acre)
20	0.210	0.732
40	0.076	0.714
60	0.051	0.981
80	0.040	0.381
100	0.032	0.211
All distances	0.000	0.560

In summary, shade over streams in the Blue Mountains appears to be more sensitive to having additional trees farther away from the stream than the Coast Range. Specifically, differences in cumulative basal area are suggested between shade categories in the Blue Mountains within 40 feet of bankfull. In the Coast Range, additional basal area may provide more shade if available 80-100 feet from bankfull, but this was not confirmed statistically (p>0.21).

STAND CHARACTERISTICS AND STREAM ASPECT

The influence of aspect on shade was discussed in an earlier section dealing with channel and valley morphology. Aspect is revisited in this section in conjunction with stand characteristics. Average shade was summarized by georegion, aspect, and stand type (Table 12). For harvested sites, east/west flowing streams had lower average shade than north/south flowing streams, especially in the Blue Mountains. There was no strong indication that shade differed by aspect for unharvested sites, though east/west flowing streams were underrepresented for that stand type.

East/west flowing streams may have a greater potential for detectable changes in shade as a result of harvest in the near-stream area. North/south flowing streams have the sun at a direct angle to the stream surface mostly during the middle of the day, while east/west streams are oriented to receive sunlight at a direct angle through most of the day. For this reason, it is more likely that a greater number of the trees along east/west streams are directly in the sun's path and shading the stream, especially on the south bank.

Table 12. Shade by aspect, harvest category, and georegion.

	Average Plot Shade (%) by Georegion and Aspect			
	Blue Mountains		Coast Range	
	E/W	N/S	E/W	N/S
Harvested	53 (-20) n=9	62 (-11) n=12	69 (-13) n=11	77 (-9) n=10
Unharvested	73 n=2	73 n=8	82 n=2	86 n=7

It stands to reason that sites with taller trees will provide more shade to the stream. Tree height was found to be a good predictor of shade levels in meadows, with shade levels decreasing as the meadow width increased (Warren 1985). Furthermore, the relationship between tree height and shade was different for those meadows with an east/west orientation rather than north/south. This same display of the ODF data is shown in Figures 26 and 27.

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. Overall, these data did not confirm the findings of Warren (1985). 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.

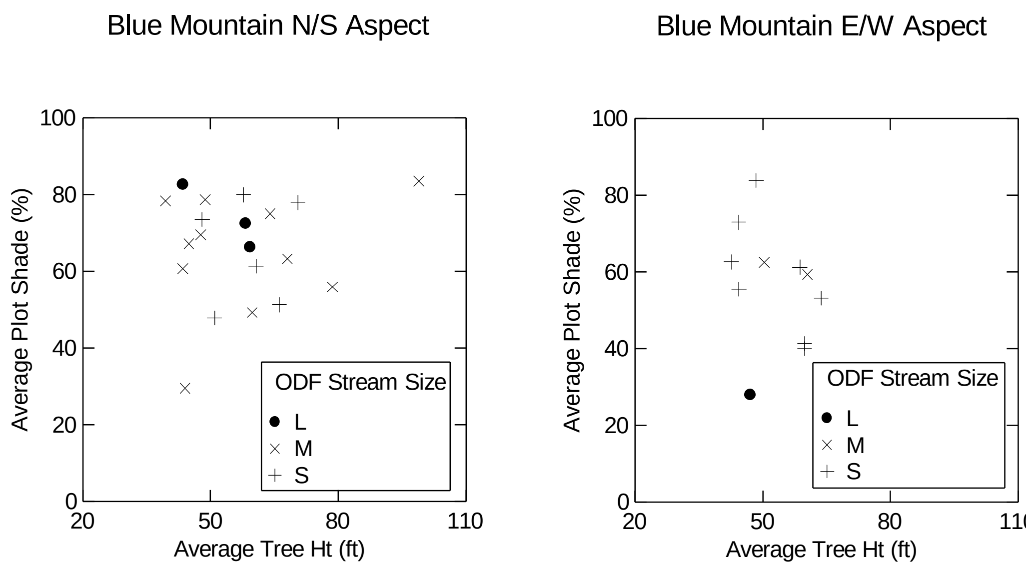


Figure 26. Stream shade over Blue Mountain streams by aspect, average tree height, and ODF stream class.

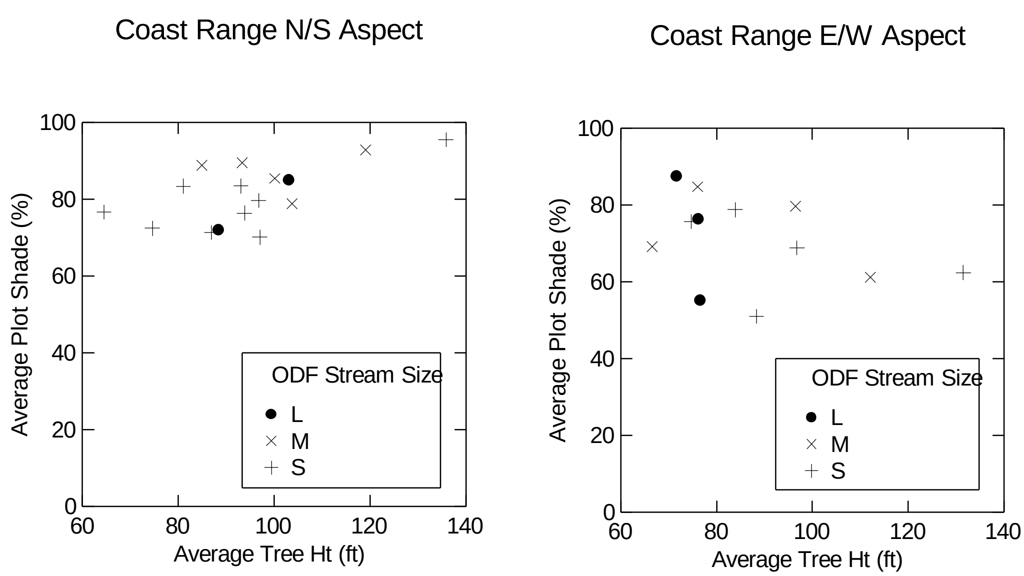


Figure 27. Stream shade over Coast Range streams by aspect, average tree height, and ODF stream class.

Though tree height did not correlate well with stream shade, basal area per acre, trees per acre, and the live crown ratio showed some promise of predicting shade after accounting for aspect. Figure 28 displays shade versus total basal area grouped by live crown ratios and aspects for each georegion.

In the Blue Mountains, there was a positive association between basal area and shade, particularly in east/west flowing streams. Grouping by the live crown ratio did not further explain shade conditions.

In the Coast Range, one shade level was produced by a wide range of basal areas and live crown ratios for north/south flowing streams. For east/west flowing streams, there was some suggestion of a curvilinear relationship between basal area and shade, especially when viewed between live crown ratio groupings. Higher live crown ratios (>40%, indicating a more open-grown stand pre-harvest) tended to have lower shade values than trees with ratios of 30% or less (possibly a more dense stand pre-harvest) at the same basal area.

Like total basal area, the trees per acre adjacent to Blue Mountain streams with an east/west aspect had a fairly strong relationship with average shade (Figure 29). No such pattern is evident in north/south streams in the georegion, and grouping by live crown ratio did not yield a readily identifiable pattern. Trees per acre for east/west flowing streams in the Coast Range again suggested a curvilinear relationship with shade that is also related to live crown ratio. Trees per acre and live crown ratio did not help explain the shade conditions found in coastal north/south flowing streams.

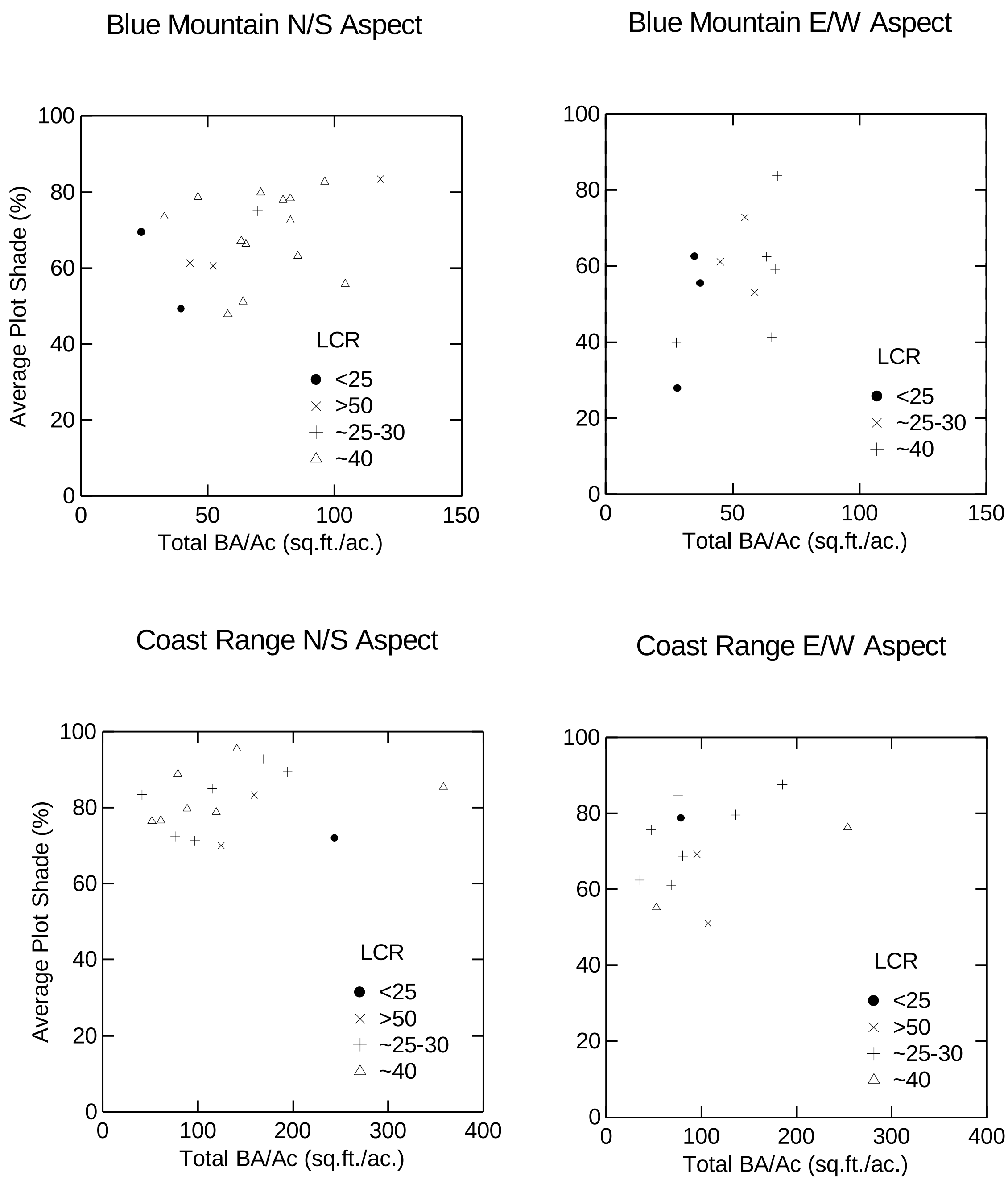


Figure 28. Shade versus basal area per acre for each georegion by aspect and live crown ratio (LCR).

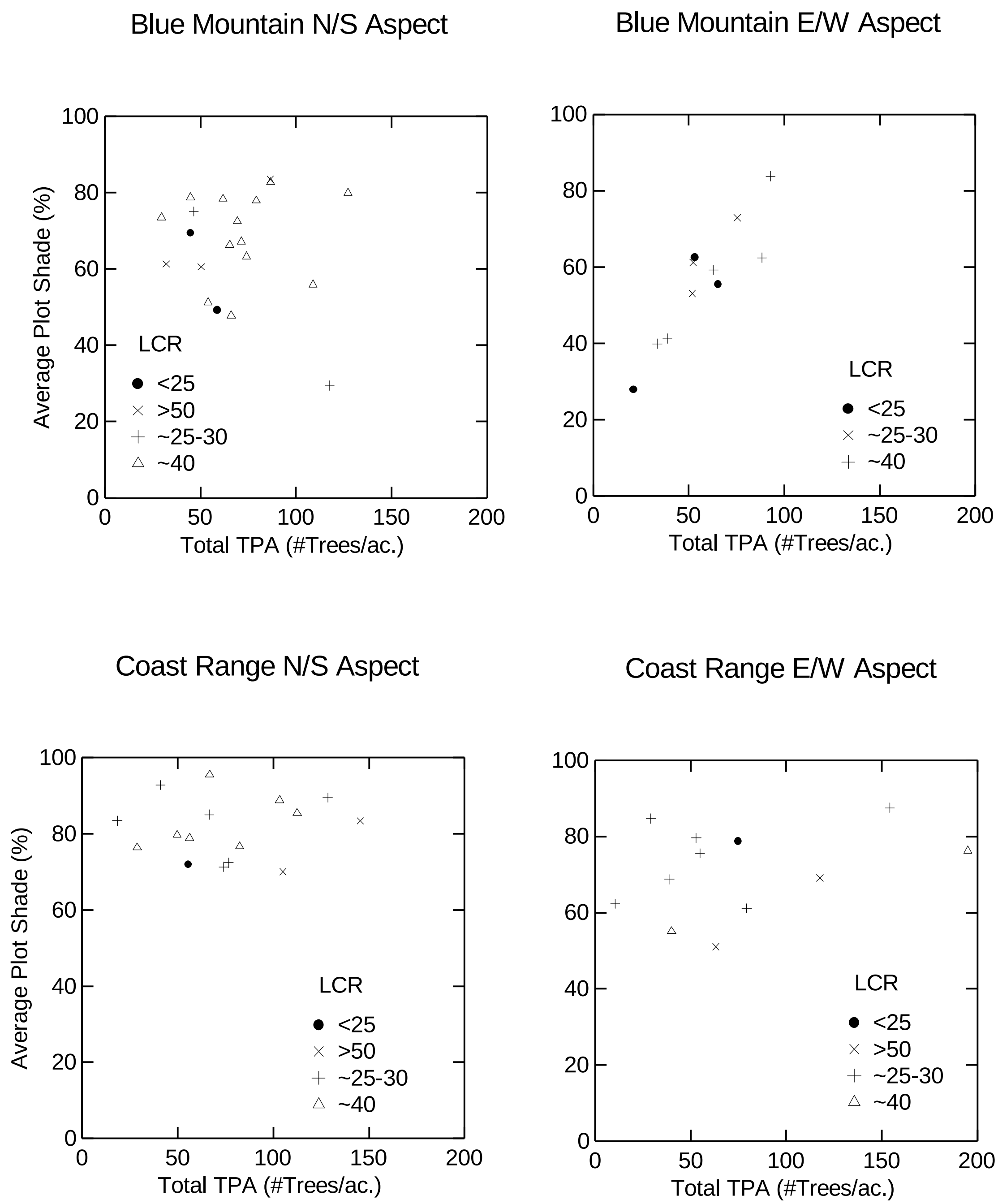


Figure 29. Shade versus trees per acre for each georegion by aspect and live crown ratio (LCR).

PROPOSED MODELS

BLUE MOUNTAINS

In light of the strong correlation between trees per acre (TPA) and shade for east/west flowing streams, a linear regression model of the TPA by streamside aspect was investigated as a predictor of shade at three feet above the water surface (using shade data collected at ten feet did not improve the model fit). The following model was produced:

Equation 1: Regression model for Blue Mountain east/west flowing streams.

Average 3 ft. Plot Shade = 17.090 + 0.268*TPA North + 0.421*TPA South
(adj. r^2 = 0.83, n=11)

The TPA on both the north and south sides of the stream were important in contributing to shade (adj. r^2 = 0.76). As will be shown in the next section, this was not the case for the Coast Range Model. The importance of the north RMA in contributing shade in the Blue Mountains may be due to the lower vegetative shade density overall than in the Coast Range. There can also be dramatic differences in the plant community from one streamside to another (i.e. sagebrush and grass versus a conifer stand) due to changes in aspect or soil, increasing the relative contribution from the heavier stocked side. This same model was tested using data for the north/south flowing streams, but was not significant (model p=0.733). Figure 30 shows the predicted shade (Equation 1) over east/west flowing streams in the Blue Mountains with different trees per acre values in each RMA.

A direct comparison of predicted shade values from Equation 1 and FPA standards is not possible because the FPA targets are expressed in basal area terms rather than TPA. However, the basal area targets can be expressed across a range of TPAs. To do this, the targets were divided by different average basal areas per tree based on a mean stand diameter (quadratic mean diameter or QMD).

Figure 31 displays how shade was predicted to vary if the different FPA standard targets were applied to stands with the same QMD. As QMD decreased and TPA increased, shade also increased. The amount of shade was also predicted to decrease with stream size (standard basal area targets decrease with decreasing stream size). Figure 31 further suggests that differences in predicted shade levels between stream size categories is greater at lower QMDs. This reflects the model's sensitivity to trees per acre, and that at small QMDs, there are greater differences in TPA than at high QMDs between stream size categories.

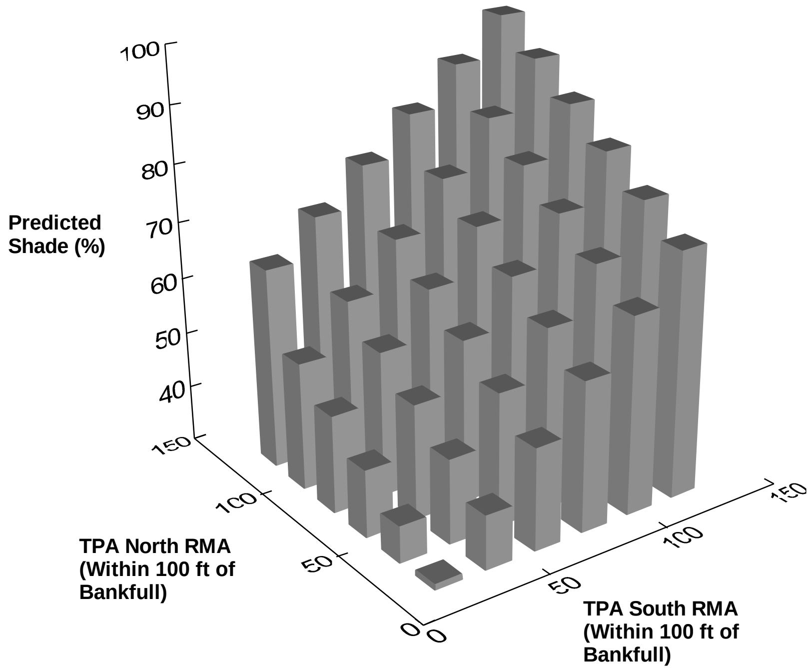


Figure 30. Predicted shade over east/west flowing Blue Mountain streams (Equation 1) across a range of live crown ratios (LCR) and basal area per acre within 100 feet of bankfull in the south RMA.

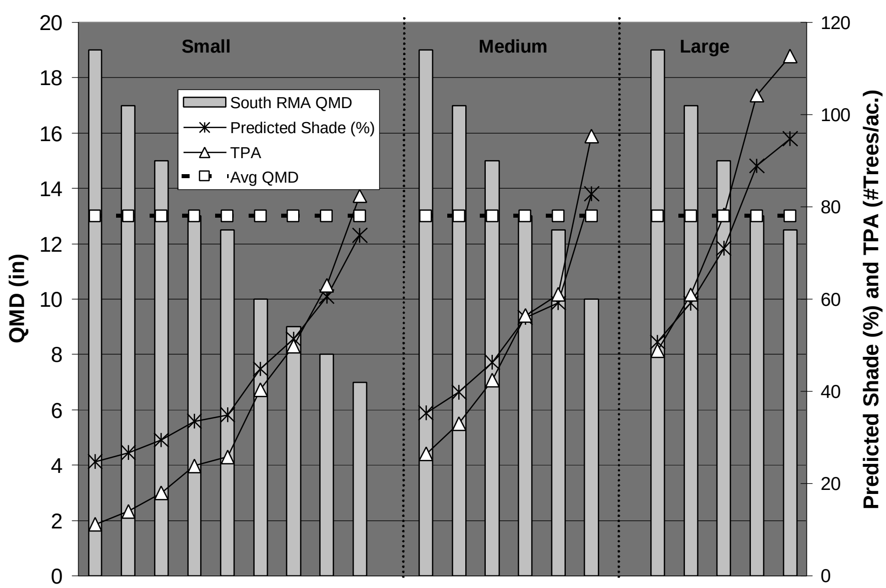


Figure 31. Predicted shade as QMD is held constant and different FPA standard basal area targets are applied for small, medium, and large streams. Calculated trees/acre (TPA) for each QMD is shown. Measured average QMD is also shown.

Again, this would follow expected stand structure characteristics where harvest adjacent to a young, dense riparian stand with high shade may result in greater changes in shade, yet maintain greater shade than when harvest is adjacent to a less dense stand of large trees with lower shade conditions overall.

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. 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.

COAST RANGE

A simple linear relationship between basal area and shade (as measured at either three feet or ten feet above the water surface) was not evident for either north/south or east/west flowing streams. However, there was a tendency for sites with higher basal area to have more shade (Figures 32A and B). Furthermore, on east/west flowing streams, the average live crown ratio for both sides of the stream appeared to be inversely related to shade (Figure 32B). Where two sites had similar live crown ratios, the site with greater basal area generally had greater shade. North/south flowing streams did not appear to display a similar association between the live crown ratio and shade (Figure 32A).

The live crown ratio and basal area per acre on both sides of east/west streams were regressed against the three-foot shade values (using ten-foot shade values did not improve model fit). The following model was produced using a backwards stepwise selection procedure.

Equation 2 : Regression model for Coast Range east/west flowing streams.

$$\text{Average \% Shade} = 96.153 - 1.041*\text{LCR} + 0.107*\text{South BA/Ac (100ft)}$$
$$(\text{adj. } r^2 = 0.656, n=12)$$

Both the live crown ratio (p=0.002) and basal area per acre on the south side of the stream (p=0.014) were stronger factors in predicting shade than basal area on the north side of the stream (p=0.922). The same model for north/south flowing streams was not significant (model p=0.665). This does not suggest that stand or landform characteristics are not linked to shade over north/south flowing streams, but that these links were not identified by this analysis.

Figure 33 displays Equation 2 results across the range of live crown ratios and stocking densities found in the data set of southern RMAs. This figure suggests that predicted shade values over east/west flowing streams were sensitive to changes in both average LCR and basal area per acre in the southern RMA, but were more responsive to LCR. Unfortunately, it would be difficult for a forest manager to develop a silvicultural prescription based on these two variables since one does not accurately predict the other. For example, the same basal area could produce small LCRs in an evenly spaced stand of small trees or a stand of larger trees arranged in patches. This same basal area could also result in a large LCR in a stand of widely spaced large trees.

In a more general sense, like the Blue Mountain model, the Coast Range model infers 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). 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.

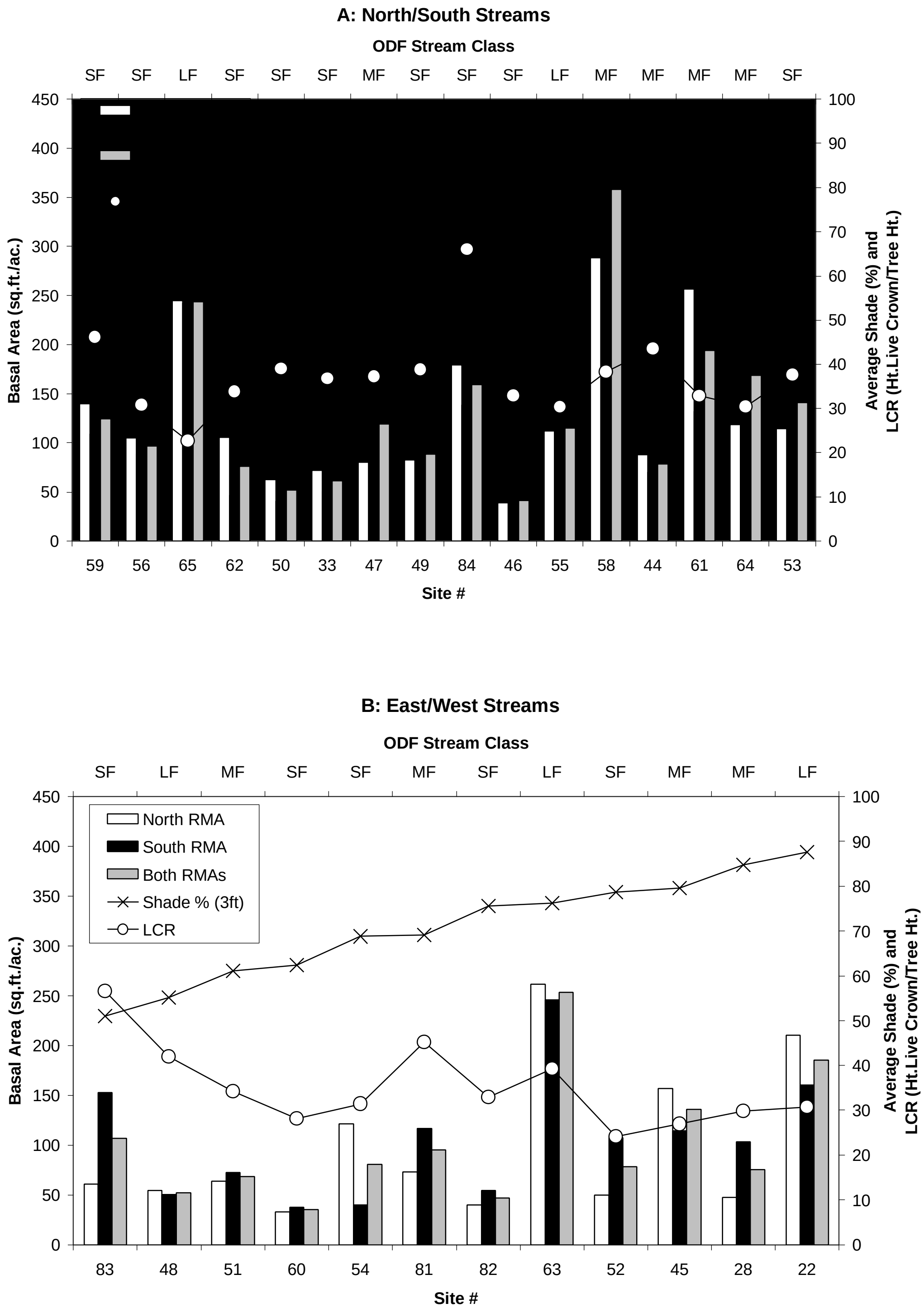


Figure 32. Coast Range basal area, shade, and average live crown ratio (LCR) for (A) north/south and (B) east/west flowing streams. Data are represented in ascending order by shade. SF = small type F stream, MF = medium type F stream, and LF = large type F stream.

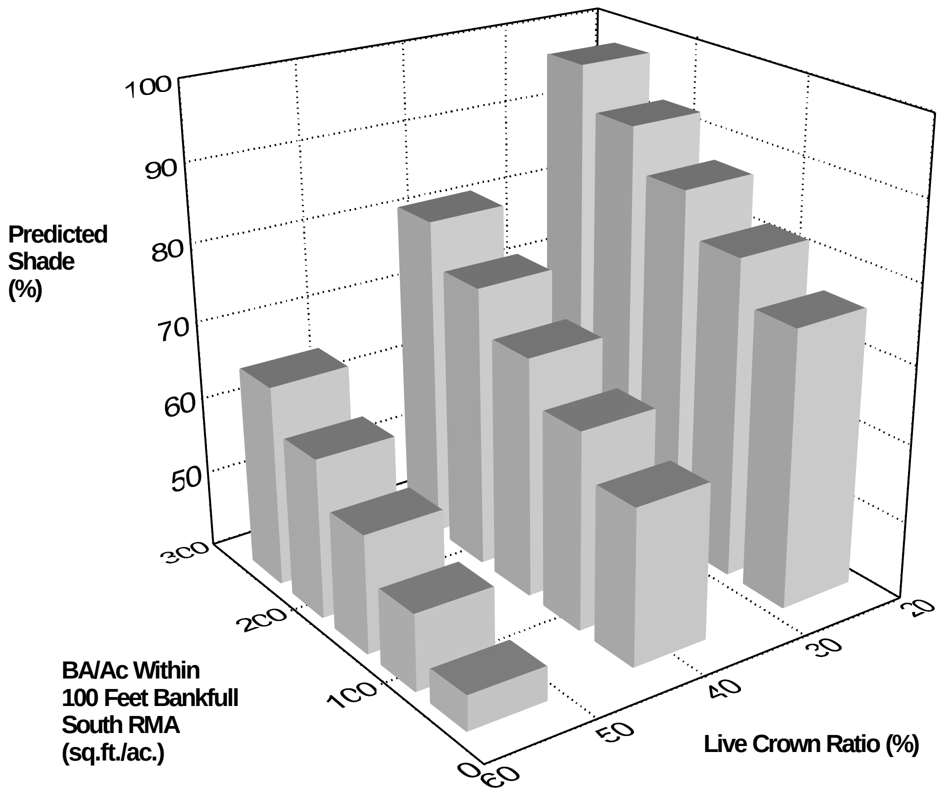


Figure 33. Predicted shade over east/west flowing Coast Range streams (Equation 2) across a range of live crown ratios (LCR) and basal areas within 100 feet of bankfull in the south RMA.

In this study, unharvested streams throughout northwest Oregon averaged 84% shade and ranged from 66-95%. In order to achieve 84% shade, the model predicts that if the southern RMA were to be harvested to the FPA standard target for clearcuts, large, medium, and small streams would require LCRs of 22, 17, and 13, respectively. It is expected that the decrease in LCR on smaller streams, accompanied by a lower standard basal area target, would result in an increase in trees per acre and reduced tree size to achieve the same level of shade. Specifically, the conditions predicted (Equation 1) to produce shade greater than 80% would be in stands with an average LCR less than 30% and basal area exceeding 200 sq.ft./ac. in the southern RMA. Of the 18 unharvested RMAs available for comparison in the Coast Range, 9 had less than 200 sq.ft./ac., 6 of the 9 sites had LCRs less than 30%. LCRs less than 30% are considered indicative of poor stand vigor.

These results indicate that, in the Coast Range, shade was sensitive to stand structure, and the greatest shade conditions were predicted to occur in dense stands with low LCRs.

The absence of a model to predict shade over north/south flowing streams does not suggest that there is no association with stand or landform characteristics, but that it was not identified by this analysis.

SUMMARY AND CONCLUSIONS

SITE CHARACTERISTICS

A total of 31 sites in the Blue Mountains and 30 sites 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. Specifically, the majority of the harvested sites were also grazed and evenly distributed between pine and fir stands, while the unharvested sites were predominantly not grazed and were on predominately white fir stands. It is critical to understand that these inherent differences between harvested and unharvested sites create 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.

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. 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 the Coast Range (+22%) georegions. 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. Thus, results from this study are most appropriately applied to a site-specific plan in the Blue Mountain georegion or sites managed with a no-cut buffer in Coast Range georegion.

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.

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 the 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 georegions, 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 were not available for comparison in this georegion.

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. 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.

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.

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.

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.

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.

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.

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.

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, this model infers 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.

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.

> *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.
>
> 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.

REFERENCES

Adams, Terry N. and K. Sullivan. 1990. *The Physics of Forest Stream Heating: A simple model*. Research Report, Project #044-5002/89/1. Weyerhaeuser. Tacoma, WA.

Amaranthus, Michael, H. Jubas, and D. Arthur. 1989. *Stream shading, summer streamflow and maximum water temperature following intense wildfire in headwater streams.* USDA Forest Service General Technical Report. 75-79.

Andrus, Chip and Henry A. Froehlich. 1988. *Riparian forest development after logging or fire in the Oregon Coast Range: Wildlife habitat and timber value. IN: Streamside Management: Riparian Wildlife and Forestry Interactions.* College of Forest Resources, University of Washington, Seattle. Institute of Forest Resources Contribution 59. Pp. 139-152.

Brazier, Jon R. and G.W. Brown. 1973. *Buffer strips for stream temperature control. Research Paper 15.* Forest Research Laboratory. Oregon State University, Corvallis, OR 97331.

Brown, George W. 1970. *Predicting the effect of clearcutting on stream temperature.* Journal of Soil and Water Conservation. 25:11-13.

Brown, George W. and J.T. Krygier. 1970. *Predicting the effect of clearcutting on stream temperature.* Journal of Soil and Water Conservation 25:11-13.

Bunnell, Fred L. and David J. Vales. 1990. *Comparison of methods for estimating forest overstory cover: differences among techniques.* Canadian Journal of Forest Research. Vol. 20. P. 101-107.

Caldwell, Jean E., K. Doughty, and K. Sullivan. 1991. *Evaluation of downstream temperature effects of type 4/5 waters.* Timber, Fish, & Wildlife Water Quality Steering Committee and Washington Department of Natural Resources. Olympia, WA.

Clark, David B., Deborah A. Clark, Paul M. Rich, Stuart Weiss, and Steven F. Oberbauer. 1996. *Landscape-scale evaluation of understory light and canopy structure: methods and application in a neotropical lowland rain forest.* Can. J. For. Res. 26: 747-757.

Commission for Environmental Cooperation (CEC). 1997. Ecological Regions of North America: *Toward a common perspective.* Commission for Environmental Cooperation 393. Rue St-Jacques Quest, Bureau 200 Montreal (Quebec) Canada H2Y 1N9. http://www.cec.org.

Cook, J.G., T.W. Stutzman, C.W. Bowers, K.A. Brenner, and L.L. Irwin. 1995. *Spherical densiometers produce biased estimates of forest canopy cover.* Wildlife Society Bulletin. 23(4):711-717.

Dent, Liz. Spring 2001 draft. *Harvest effects on riparian function and structure under the 1994 forest practice riparian rules.* Oregon Department of Forestry, Technical Report 8. 59p.

Department of Environmental Quality. 1995. *Water Quality Standards Review 1192-1994. Final Issue Papers.* Standards and Assessment Section. Portland, Oregon 97204.

Drake, Douglas. 1999. *Oregon Coast Range REMAP Study: Stream Habitat Index Development and Site Results 1994 – 1996.* Oregon Department of Environmental Quality. Technical Report No. BIO98-06. 23pp.

Englund, Sylvia R., Joseph J. O'Brian, and David B. Clark. 2000. *Evaluation of digital and film hemispherical photography and spherical densiometry for measuring forest light environments.* Can. J. For. Res. Vol. 30. Pp. 1999-2005.

Evans, G.C. and D.E. Coombe. 1959. *Hemispherical and woodland canopy photography and the light climate.* Journal of Ecology. Vol. 47 p.103-113.

Feller, M.C. 1981. *Effects of clearcutting and slashburning on stream temperature in southwestern British Columbia.* Water Resources Bulletin 17(5):863-867.

Hairston-Strang, Anne B. and Paul W. Adams. 2000. *Riparian management area condition for timber harvests conducted before and after the 1994 Oregon water protection rules.* Western Journal of American Forestry. 15 (3) pp.147-153

HemiView Users Manual. *No. 2.0. Delta-T Devices Ltd.* Burwell, Cambridge, Britain.

Hewlett, John D. and J.C. Fortson. 1982. *Stream temperature under an inadequate bufferstrip in the southeast Piedmonts.* Water Resources Bulletin 18(6):983-988.

Johnson, Sherri L. and Julia A. Jones. 2000. *Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon.* Canadian Journal of Fisheries and Aquatic Science. 57:1-10.

Kappel, William A. and D.R. DeWalle. 1975. *Calculating stream temperature response to vegetative shade removal on selected small Pennsylvania streams.* Research Brief 9. School of Forest Resources, Pennsylvania State University. 1-3.

Levno, Al and J. Rothacher. 1967. *Increases in maximum stream temperatures after logging in old-growth Douglas-fir watersheds.* USDA Research Note PNW-65. Pacific Northwest Forest and Range Experiment Station. Portland, OR. 12 pp.

Lynch, James A., E.S. Corbett, and K. Mussallem. 1985. *Best management practices for controlling nonpoint source pollution on forested watersheds.* Journal of Soil and Water Conservation. 164-167.

Meehan, William R. 1970. *Some effects of shade cover on stream temperature in southeast Alaska. USDA Research Note PNW-113.* Pacific Northwest Forest and Range Experiment Station. Portland, OR. 9 pp.

Minore, Don and Howard G. Weatherly. 1994. *Riparian trees, shrubs, and forest regeneration in the coastal mountains of Oregon.* New Forests. 8:249-263.

Murphy, Michael L., Charles P. Hawkins, and N. H. Anderson. 1981. *Effects of canopy modification and accumulated sediment on stream communities.* Transactions of the American Fisheries Society. 110(4): 469-478.

Nierenberg, Tara R. and David E. Hibbs. 2000. *A characterization of unmanaged riparian areas in central Coast Range of western Oregon.* Forest Ecology and Management 129 (2000) 195-206.

Nuttle, Tim. 1997. *Densiometer bias? Are we measuring the forest or the trees?* Wildlife Society Bulletin. 25(3):610-611.

Oliver, Chadwick D. and Bruce C. Larson. 1996. *Forest Stand Dynamics.* John Wiley and Sons, Inc. 520pp.

Oregon Department of Forestry. Personal communication, Josh Robben. Preliminary results from *the BMP Compliance Monitoring Project Final 2000-2001 Study*. 2600 State Street, Salem, Oregon 97310. (503) 945-7470

Oregon Forest Practices Act. 1971. May 1998. Oregon Secretary of State, State Capitol, Salem, Oregon 97310. 25 pp.

Oregon Watershed Enhancement Board (OWEB). 2001. *Water Quality Monitoring: Technical Guide Book.* Chapter 14: Stream Shade and Canopy Cover Monitoring Methods. Addendum. 47p.

Pabst, Robert J. and Thomas A. Spies. 1999. *Structure and composition of unmanaged riparian forests in the coastal mountains of Oregon, U.S.A.* Canadian Journal Forest Resources. Vol. 29. Pp.1557-1573.

Rashin, Ed and Craig Graber. Timber, Fish, & Wildlife (TFW). 1992. *Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature.* Washington State Department of Ecology. TFW-WQ6-92-001. 59p. plus appendices.

Robinson, M. W. 1947. *An instrument to measure forest crown cover.* For. Chron. 23:222-225.

Rosgen, David L. 1994. *A classification of natural rivers.* Catena (1994) 22 169-199

Roxburgh, Jason R. and Dave Kelly. 1995. *Uses and limitations of hemispherical photography for estimating forest light environments.* New Zealand Journal of Ecology. 19(2):213-217.

Sullivan, Kathleen, J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen. 1990. *Evaluation of Prediction Models and Characterization of Stream Temperature Regimes in Washington.* Timber, Fish, & Wildlife, Project #TFW-WQ3-90-006. Washington Department of Natural Resources, Forest Regulation and Assistance. Olympia, WA 98504. 229pp.

Thom, B.A., K. K. Jones, and R. L. Flitcroft. 1999. *Stream Habitat Conditions in Western Oregon.* Monitoring Program Report 1999-1 to the Oregon Plan for Salmon and Watersheds, Governor's Natural Resources Office, Salem, Oregon.

Warren, M.S. 1985. *The influence of shade on butterfly numbers in woodland rides, with special reference to the Wood White Leptidea sinapis.* Biological Conservation. 33:147-164.

Whitmore, T. C., N. D. Brown, M. D. Swaine, D. Kennedy, C. I. Goodwin-Bailey, and W. K. Gong. 1993. Journal of Tropical Ecology. 9:131-15

APPENDIX A: SITE INFORMATION SUMMARIES

SITE INFORMATION SUMMARIES

Table A-1: General stand and disturbance information.

						Legal Location			O	
SiteID	Georegion	Stand Type	Stream Class*	Harvest Type	RMA** Prescription	T	R	S	Grazing	F
20	Coast Range	Harvested	MF	Clearcut	BW	12S	08W	32	No	
21	Blue Mountain	Harvested	SF	Thin	SS	04S	29E	11	Yes	Y
22	Coast Range	Unharvested	LF	NA	NA	08N	08W	35	No	
25	Coast Range	Harvested	LF	Clearcut	BW	08N	08W	35	No	
28	Coast Range	Harvested	MF	Clearcut	BW	15S	08W	02	No	
29	Blue Mountain	Harvested	SF	Thin	SS	05N	44E	03	Yes	
30	Blue Mountain	Harvested	MF	Thin	SS	04N	41E	13, 14, 24	No	Y
31	Blue Mountain	Harvested	LF	Thin	SS	01N	34E	22	Yes	Y
32	Blue Mountain	Harvested	SF	Clearcut	SS	04S	29E	10	Yes	
33	Coast Range	Harvested	SF	Clearcut	BW	07S	10W	4	No	
34	Blue Mountain	Harvested	MF	Thin	SS	06S	30E	17	Yes	
35	Blue Mountain	Late Seral	MF	NA	NA	04N	39E	3	No	
36	Blue Mountain	Harvested	SF	Thin	SS	05S	41E	30	Yes	
37	Blue Mountain	Harvested	SF	Thin	SS	05S	41E	30	Yes	
38	Blue Mountain	Harvested	MF	Thin	SS	05S	41E	20	Yes	
40	Blue Mountain	Unharvested	SF	NA	NA	02N	43E	36	Yes	
41	Blue Mountain	Harvested	SF	Thin	BW	02N	43E	36	Yes	
42	Blue Mountain	Harvested	MF	Thin	SS	05S	31E	17	Yes	
44	Coast Range	Harvested	MF	Clearcut	SS	14S	08W	36	No	
45	Coast Range	Harvested	MF	Clearcut	SS	07S	09W	20	No	
46	Coast Range	Harvested	SF	Clearcut	RCR	07S	09W	19	No	
47	Coast Range	Harvested	MF	Clearcut	BW	05N	05W	01	No	Y

						Legal Location			O	
SiteID	Georegion	Stand Type	Stream Class*	Harvest Type	RMA** Prescription	T	R	S	Grazing	F
48	Coast Range	Harvested	LF	Clearcut	SS	01S	08W	01	No	
49	Coast Range	Harvested	SF	Clearcut	BW	05N	01W	19	No	
50	Coast Range	Harvested	SF	Clearcut	BW	05N	05W	35	No	
51	Coast Range	Harvested	MF	Clearcut	RCR	07N	05W	32	No	
52	Coast Range	Harvested	SF	Clearcut	BW	06N	04W	18	No	
53	Coast Range	Late Seral	SF	NA	NA	14S	08W	35	No	
54	Coast Range	Harvested	SF	Clearcut	BW	04N	08W	01	No	
55	Coast Range	Late Seral	LF	NA	NA	14S	07W	19	No	
56	Coast Range	Harvested	SF	Clearcut	BW	03S	10W	03	No	
58	Coast Range	Late Seral	MF	NA	NA	12S	07W	29	No	
59	Coast Range	Harvested	SF	Clearcut	BW	03S	10W	18	No	
60	Coast Range	Harvested	SF	Clearcut	BW	12S	08W	36	No	
61	Coast Range	Late Seral	MF	NA	NA	13S	08W	27	No	
62	Coast Range	Harvested	SF	Clearcut	BW	03S	10W	13	No	
63	Coast Range	Unharvested	LF	NA	NA	05N	10W	33	No	
64	Coast Range	Late Seral	MF	NA	NA	12S	08W	36	No	
65	Coast Range	Late Seral	LF	NA	NA	14S	07W	29	No	
66	Blue Mountain	Harvested	SF	Thin	SS	02N	44E	32	Yes	
67	Blue Mountain	Late Seral	MF	NA	NA	03N	37E	18	No	
68	Blue Mountain	Harvested	MF	Thin	SS	04N	41E	13	Yes	Y
69	Blue Mountain	Unharvested	MF	NA	NA	02N	45E	21	Yes	
70	Blue Mountain	Harvested	SF	Thin	SS	02N	46E	6	Yes	
71	Blue Mountain	Harvested	MF	Thin	BW	02N	43E	3	Yes	
72	Blue Mountain	Late Seral	MF	NA	NA	02N	37E	7	No	
74	Blue Mountain	Harvested	SF	Thin	SS	01N	34E	36	Yes	
75	Blue Mountain	Unharvested	MF	NA	NA	02N	37E	5	No	
76	Blue Mountain	Late Seral	LF	NA	NA	03N	37E	22	No	

						Legal Location			O	
SiteID	Georegion	Stand Type	Stream Class*	Harvest Type	RMA** Prescription	T	R	S	Grazing	F
77	Blue Mountain	Late Seral	LF	NA	NA	03N	37E	22	No	
78	Blue Mountain	Unharvested	SF	NA	NA	03N	43E	34	No	
79	Blue Mountain	Harvested	MF	Thin	SS	05S	31E	09	Yes	
80	Blue Mountain	Late Seral	MF	NA	NA	02N	37E	10	No	
81	Coast Range	Harvested	MF	Clearcut	BW	06S	10W	14	No	
82	Coast Range	Harvested	SF	Clearcut	BW	06S	10W	14	No	
83	Coast Range	Harvested	SF	Clearcut	BW	05N	10W	23	No	
84	Coast Range	Unharvested	SF	NA	NA	05N	10W	23	No	
85	Blue Mountain	Harvested	SF	Clearcut	SS	01S	35E	04	No	
86	Blue Mountain	Harvested	SF	Thin	SS	17S	29E	06	Yes	Y
87	Blue Mountain	Harvested	SF	Thin	SS	14S	30E	24	No	
88	Blue Mountain	Harvested	LF	Thin	SS	14S	35E	34	No	

* SF = small fish-bearing stream, MF = medium fish-bearing stream, LF = large fish-bearing stream
** NA = Not applicable, BW = No-cut buffer, RCR = riparian conifer restoration, SS= site specific

Table A-2: Stand age, tree height, live crown ratio, and dominant vegetation.

Site ID	Avgerage Overstory Hardwood Age (yrs)	Average Overstory Conifer Age (yrs)	Average Conifer Height (ft)	Average Hardwood Ht (ft)	Average Tree Ht (ft)	Average Hardwood LCR (%)	Average. Conifer LCR (%)	Average LCR (%)
20	60	104	100	83	98	26	46	4
21	100		71		71		37	3
22	55	75	59	84	80	32	24	3
25	60	125	68	96	88	54	42	5
28	50	70	73	79	77	29	31	3
29	35	36	50	39	49	34	28	2
30		104	60		60		23	2
31		68	62	32	60	16	21	2
32		123	60		60		35	3
33			59	70	69	36	39	3
34		100	44		44		26	2
35			82	116	83	43	62	6
36			66		66		40	4
37			61		61		47	4
38			62	25	61	36	51	5
40		60	43		43		18	1
41			59		59		32	3
42			61		61		36	3
44	27	90	85	85	85	44	33	4
45	45	80	91	102	99	29	21	2
46	49	56	67	120	108	31	40	3
47	50	90	124	83	98	36	40	3
48	35	50	72	81	80	43	33	4
49	45	70	98	96	96	41	30	3
50		55	108	79	106	33	39	3

Site ID	Avgerage Overstory Hardwood Age (yrs)	Average Overstory Conifer Age (yrs)	Average Conifer Height (ft)	Average Hardwood Ht (ft)	Average Tree Ht (ft)	Average Hardwood LCR (%)	Average. Conifer LCR (%)	Average LCR (%)
51	35	55	139	86	87	34	40	3
52	35	44	81	87	86	22	45	2
53	30	100	187	84	110	39	34	3
54	45	55	109	85	92	28	38	3
55	25	100	130	76	84	32	23	3
56	40	51	86	88	86	16	37	3
58		100	122	78	121	40	38	3
59	45	46	103	91	99	45	47	4
60	67	92	126	137	128	28	28	2
61	50	100	100	86	89	36	16	3
62	30	35	80	69	75	32	35	3
63	43	120	68	84	79	44	29	3
64	60	100	144	94	129	17	36	3
65	55	80	93	84	89	23	22	2
66		107	44		44		24	2
67	53	160	79	49	73	38	30	3
68		26	48		48		24	2
69		50	68		68		44	4
70		55	51		51		35	3
71		78	57	44	57	14	37	3
72	21	25	48	31	46	35	44	4
74		29	64		64		32	3
75	23	32	46	44	45	45	32	3
76	51	49	71	47	60	47	35	4
77	25	82	74	43	66	38	37	3
78		92	48		48		40	4
79		92	65	92	66	37	42	4

Site ID	Avgerage Overstory Hardwood Age (yrs)	Average Overstory Conifer Age (yrs)	Average Conifer Height (ft)	Average Hardwood Ht (ft)	Average Tree Ht (ft)	Average Hardwood LCR (%)	Average. Conifer LCR (%)	Average LCR (%)
80	23	37	57	41	56	56	40	4
81	30	43	58	75	72	46	44	4
82	35	45	67	82	79	35	25	3
83	31	53	98	79	93	56	57	5
84	25	32	81	81	81	71	63	6
85			58		58		41	4
86		53	60		60		38	3
87	88	53	71		71		41	4
88	43	29	61		61		44	4

Table A-3: Whole- and half-plot basal area and trees per acre.

SiteID	Whole Plot Area (ac)	Whole Plot BA/Ac (sq.ft./ac.)	Whole Plot TPA (#Trees/ac.)	Half Plot Area (ac)	Half Plot BA/Ac (sq.ft./ac.)			
					East	West	North	South
20	2.3	35.0	13.5	1.1	26.9	43.2		
21	2.3	79.6	79.3	1.1	69.7	89.6		
22	2.3	185.1	154.2	1.1			210.0	160.1
25	2.3	157.2	71.4	1.1			109.4	205.1
28	2.3	75.4	29.2	1.1			47.4	103.4
29	2.3	54.7	75.4	1.1			59.5	49.9
30	2.3	39.6	58.8	1.1	50.1	29.1		
31	4.6	28.2	21.1	2.3			43.0	13.4
32	2.3	27.8	33.5	1.1			23.1	32.5
33	2.3	61.2	82.3	1.1	71.9	50.6		
34	2.3	49.7	117.6	1.1	55.2	44.2		
35	3.7	118.1	86.6	1.8	112.3	123.8		
36	2.3	63.9	54.0	1.1	63.7	64.2		
37	2.3	43.0	32.2	1.1	42.8	43.2		
38	3.7	52.1	50.4	1.8	50.7	53.6		
40	2.3	35.0	53.1	1.1			35.7	34.2
41	2.3	45.2	52.3	1.1			22.3	68.0
42	3.7	66.8	62.9	1.8			51.2	82.3
44	3.7	78.8	103.2	1.8	87.7	70.0		
45	4.6	135.7	52.9	2.3			156.9	114.5
46	2.3	41.2	18.3	1.1	39.1	43.3		
47	3.7	119.3	56.1	1.8	80.2	158.5		
48	3.7	52.4	40.0	1.8			54.5	50.4
49	2.3	88.5	49.7	1.1	82.9	94.1		
50	2.3	51.7	28.7	1.1	62.6	40.8		
51	2.3	68.3	79.3	1.1			64.0	72.6
52	2.3	78.5	74.9	1.1			49.8	107.3

SiteID	Whole Plot Area (ac)	Whole Plot BA/Ac (sq.ft./ac.)	Whole Plot TPA (#Trees/ac.)	Half Plot Area (ac)	Half Plot BA/Ac (sq.ft./ac.)			
					East	West	North	South
53	2.3	140.8	66.6	1.1	114.3	167.2		
54	2.3	80.5	38.8	1.1			121.1	39.9
55	3.7	115.0	66.4	1.8	112.1	117.9		
56	2.3	96.7	74.1	1.1	105.0	88.3		
58	3.7	358.0	112.4	1.8	288.8	427.2		
59	2.3	124.3	105.0	1.1	139.7	109.0		
60	2.3	35.1	10.5	1.1			32.8	37.4
61	3.7	194.2	128.5	1.8	256.6	131.9		
62	2.3	76.0	76.7	1.1	105.3	46.7		
63	4.6	253.7	194.9	2.3			261.6	245.7
64	2.3	168.8	40.9	1.1	118.7	219.0		
65	4.6	243.7	55.5	2.3	245.0	242.4		
66	2.3	37.2	65.3	1.1			35.9	38.6
67	3.7	69.7	46.6	1.8	79.9	59.6		
68	2.3	23.9	44.9	1.1	21.0	26.9		
69	2.8	85.6	74.1	1.4	70.3	100.8		
70	2.3	58.0	66.2	1.1	73.2	42.7		
71	3.7	63.4	88.2	1.8			96.0	30.7
72	2.3	82.6	61.9	1.1	114.0	51.1		
74	2.3	58.6	51.8	1.1			88.5	28.6
75	2.3	63.2	71.4	1.1	57.2	69.1		
76	4.6	65.1	65.3	2.3	59.4	70.8		
77	3.7	82.7	69.4	1.8	104.4	61.0		
78	2.3	67.5	92.8	1.1			92.4	42.6
79	3.7	104.3	108.9	1.8	117.6	90.9		
80	2.3	46.2	44.9	1.1	63.6	28.7		
81	2.3	95.2	117.6	1.1			73.5	116.9
82	2.3	47.1	54.9	1.1			39.6	54.5
83	2.3	107.0	63.2	1.1			61.2	152.7

SiteID	Whole Plot Area (ac)	Whole Plot BA/Ac (sq.ft./ac.)	Whole Plot TPA (#Trees/ac.)	Half Plot Area (ac)	Half Plot BA/Ac (sq.ft./ac.)			
					East	West	North	South
84	2.3	159.2	145.5	1.1	179.6	138.7		
85	2.3	71.0	127.2	1.1	46.1	95.9		
86	2.3	65.4	38.8	1.1			85.7	45.0
87	2.3	33.0	29.6	1.1	32.9	33.0		
88	4.6	96.2	86.7	2.3	85.3	107.1		

APPENDIX B: SHADE AND COVER SUMMARY INFORMATION BY SITE

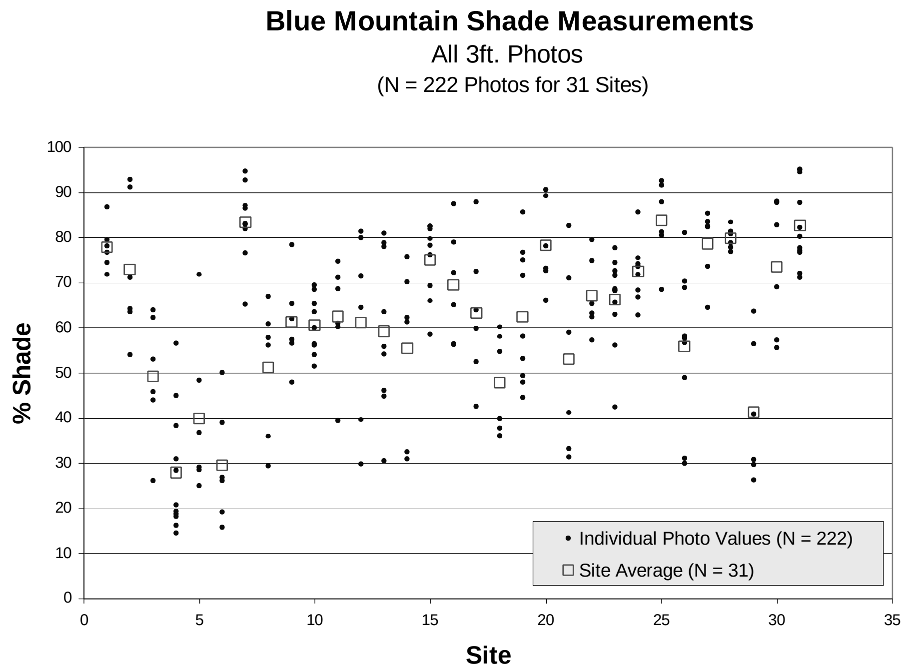
SHADE AND COVER SUMMARY INFORMATION BY SITE.

Table B-1: Average, maximum, minimum, and standard deviation for shade and cover by site.

SiteID	Georegion	Avg. Shade %	Max Shade %	Min Shade %	SD Shade %	Avg Cover %	Max Cove
20	Coast Range					75	
21	Blue Mountain	78	87	72	4.8	92	
22	Coast Range	88	94	77	6.2		
25	Coast Range					77	
28	Coast Range	85	98	70	11.3	92	
29	Blue Mountain	73	93	54	14.7	75	
30	Blue Mountain	49	64	26	13.0	43	
31	Blue Mountain	28	57	14	13.0	21	
32	Blue Mountain	40	72	25	16.4	48	
33	Coast Range	77	87	61	9.5	95	
34	Blue Mountain	29	50	16	11.9	25	
35	Blue Mountain	83	95	65	8.3	92	
36	Blue Mountain	51	67	29	13.9	54	
37	Blue Mountain	61	78	48	9.5	69	
38	Blue Mountain	61	69	51	6.2	85	
40	Blue Mountain	63	75	39	11.7	49	
41	Blue Mountain	61	81	30	20.0	63	
42	Blue Mountain	59	81	30	16.7	55	
44	Coast Range	89	96	82	4.8	98	
45	Coast Range	80	91	52	10.9	92	
46	Coast Range	83	94	65	9.6	95	
47	Coast Range	79	90	57	10.5	98	
48	Coast Range	55	83	31	14.7	83	
49	Coast Range	80	89	69	7.4	99	
50	Coast Range	76	88	61	9.3	94	

SiteID	Georegion	Avg. Shade %	Max Shade %	Min Shade %	SD Shade %	Avg Cover %	Max Cove
51	Coast Range	61	73	52	7.7	89	
52	Coast Range	79	86	70	7.3	98	
53	Coast Range	95	98	91	2.3	100	
54	Coast Range	69	88	54	11.6	91	
55	Coast Range	85	93	78	5.5	98	
56	Coast Range	71	83	60	7.5	95	
58	Coast Range	85	91	78	4.3	99	
59	Coast Range	70	83	64	6.2	94	
60	Coast Range	62	84	45	16.8	78	
61	Coast Range	89	95	83	2.9	100	
62	Coast Range	72	80	58	8.1	97	
63	Coast Range	76	83	64	6.3	98	
64	Coast Range	93	98	80	6.2	99	
65	Coast Range	72	96	51	14.1	91	
66	Blue Mountain	55	76	31	17.7	63	
67	Blue Mountain	75	83	59	8.1	97	
68	Blue Mountain	69	87	56	11.6	75	
69	Blue Mountain	63	88	43	14.6	68	
70	Blue Mountain	48	60	36	10.2	72	
71	Blue Mountain	62	86	44	14.2	60	
72	Blue Mountain	78	91	66	9.0	80	
74	Blue Mountain	53	83	31	19.6	78	
75	Blue Mountain	67	80	57	7.8	71	
76	Blue Mountain	66	78	42	9.4	74	
77	Blue Mountain	72	86	63	6.1	92	
78	Blue Mountain	84	93	68	8.4	84	
79	Blue Mountain	56	81	30	16.3	73	
80	Blue Mountain	79	85	65	7.5	86	
81	Coast Range	69	81	46	12.1	88	
82	Coast Range	76	90	68	7.0	88	

SiteID	Georegion	Avg. Shade %	Max Shade %	Min Shade %	SD Shade %	Avg Cover %	Max Cove
83	Coast Range	51	61	39	8.4	67	
84	Coast Range	83	93	81	4.5	99	
85	Blue Mountain	80	83	77	2.3	94	
86	Blue Mountain	41	64	26	14.3	43	
87	Blue Mountain	73	88	56	13.8	89	
88	Blue Mountain	83	95	71	8.7	91	



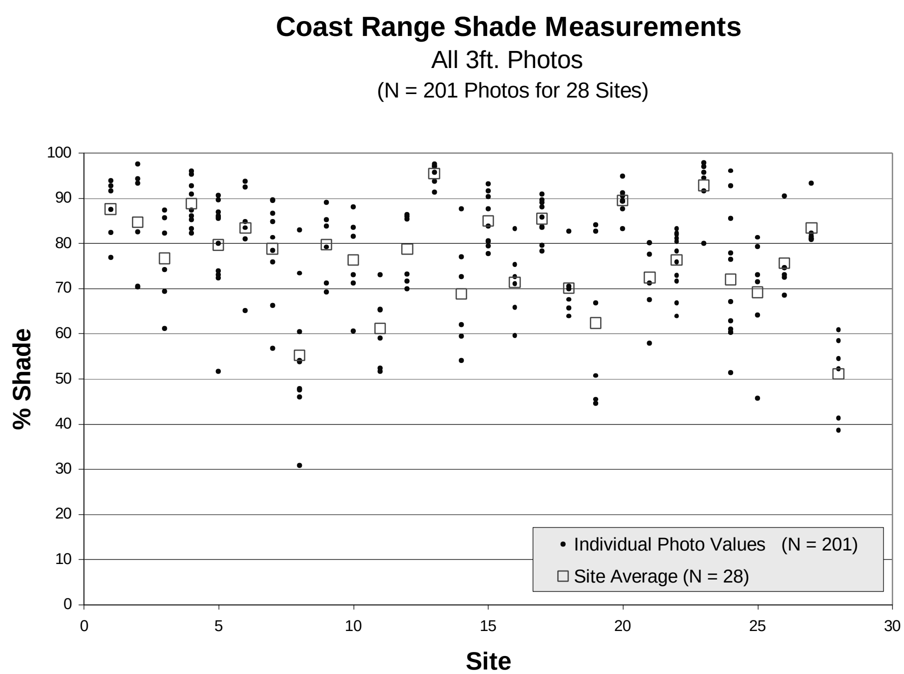


Figure B-1: Individual and average three-foot shade measurements for the Blue Mountain and Coast Range georegions.

APPENDIX C: VALLEY AND CHANNEL MORPHOLOGY RELATIONSHIPS TO SHADE

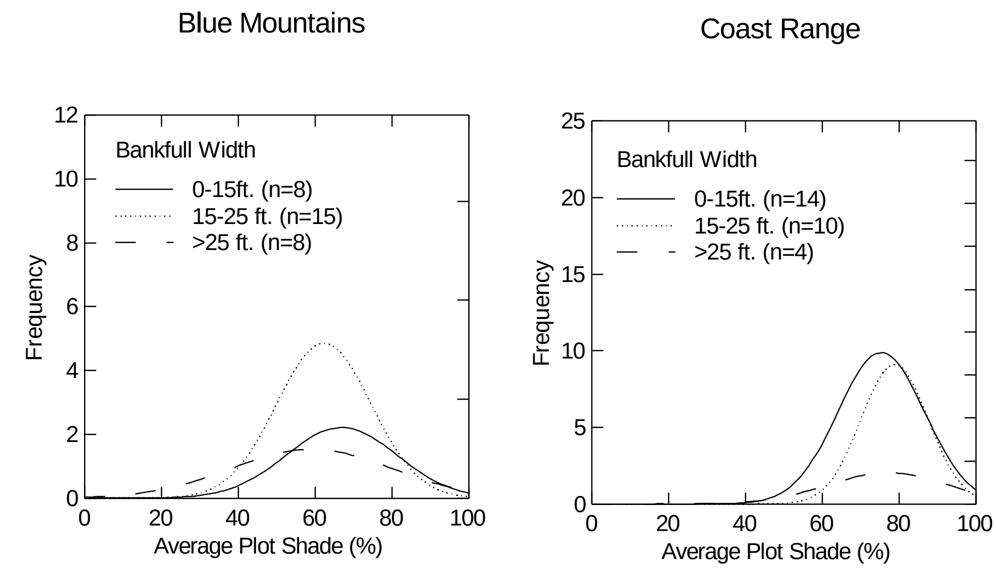


Figure C-1: Frequency of shade values by bankfull width categories and georegion.

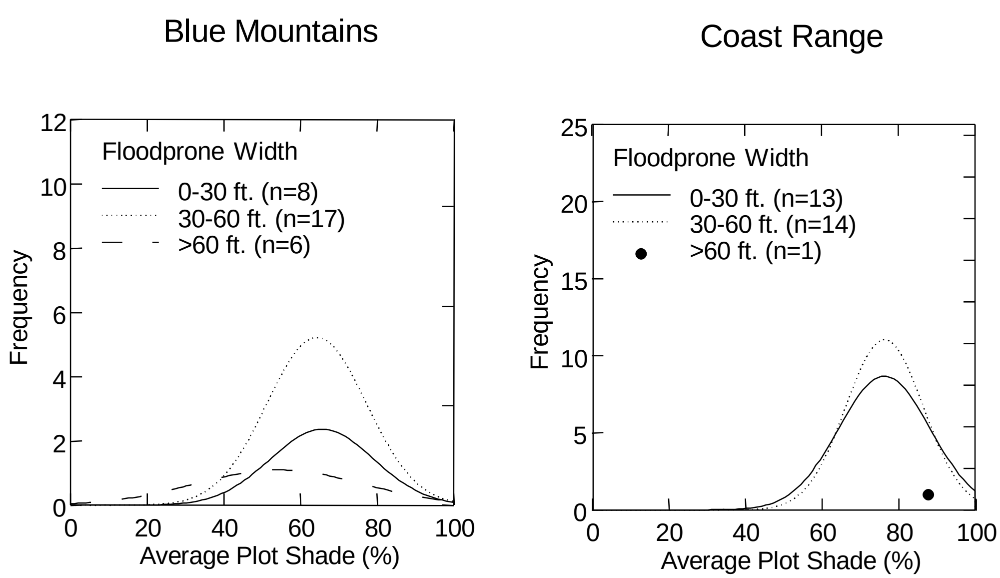


Figure C-2: Frequency of shade values by floodprone width categories and georegion.

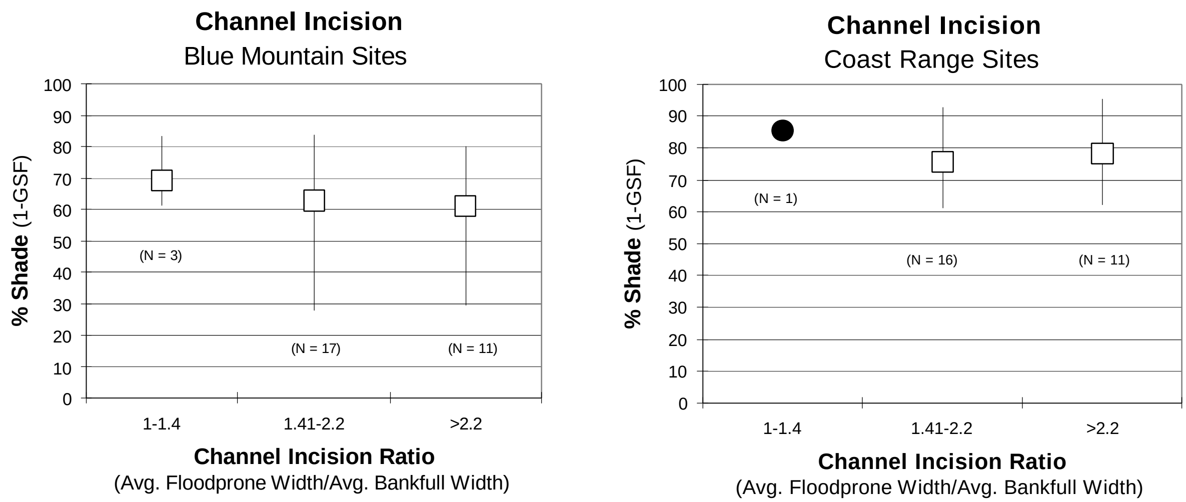


Figure C-3. Channel incision category versus shade by georegion.

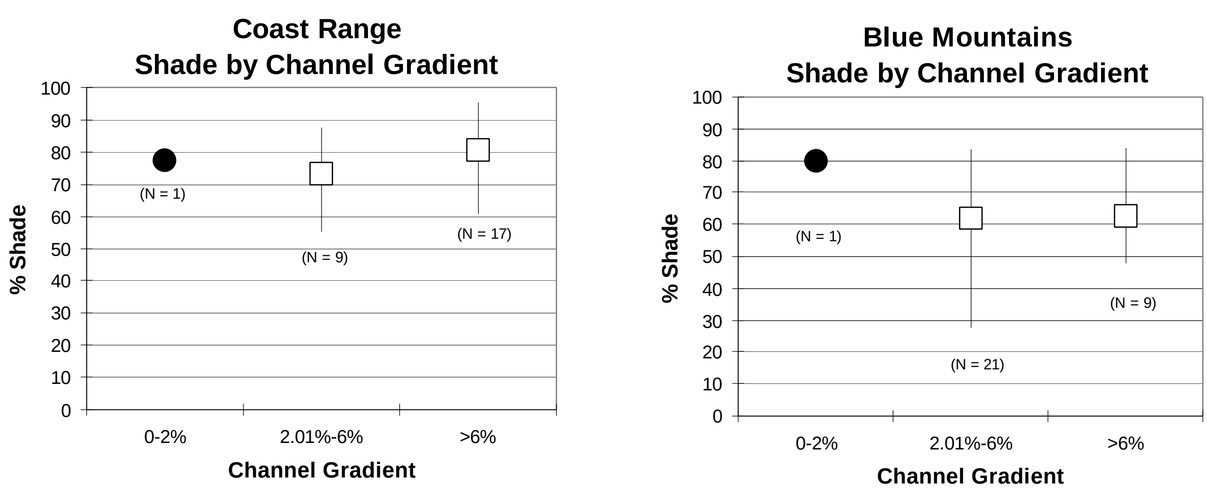


Figure C-4. Shade versus channel gradient by georegion.

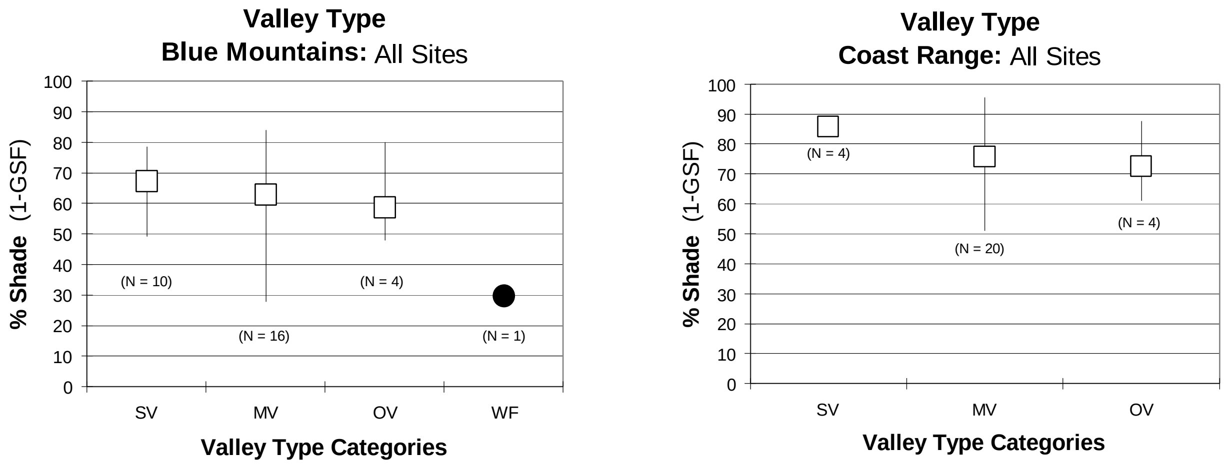


Figure C-5. Shade versus valley type by georegion.

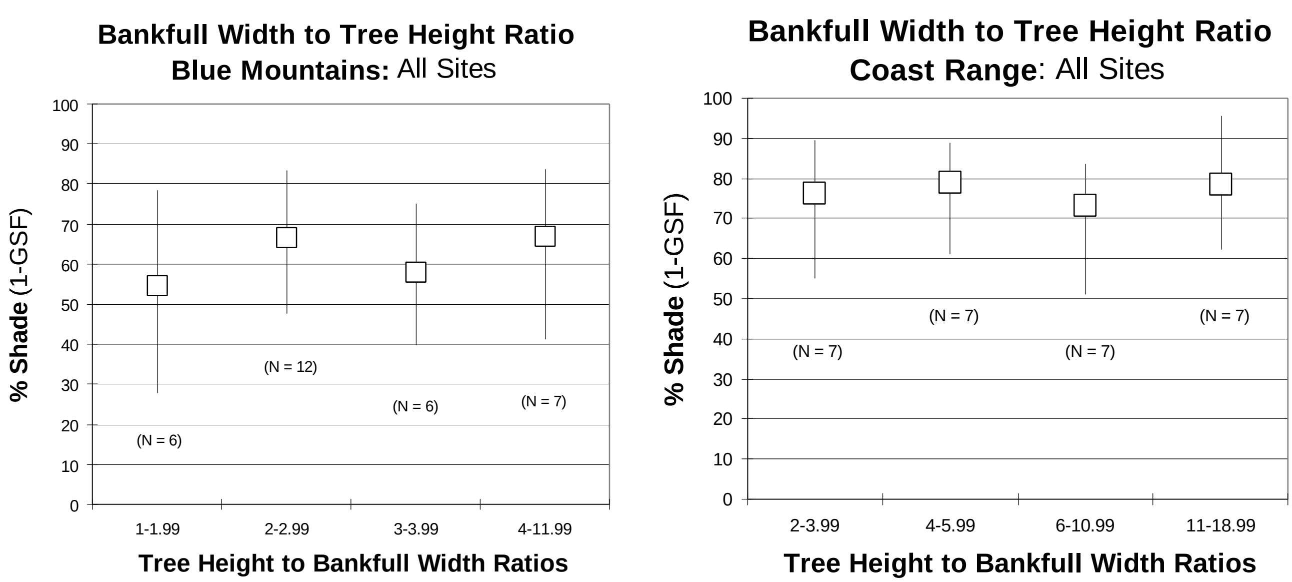


Figure C-6. Shade versus bankfull-width-to-tree-height ratio by georegion.

APPENDIX D: VEGETATION TYPE AND SHADE

AVERAGE PLOT SHADE BY STAND SPECIES COMPOSITION

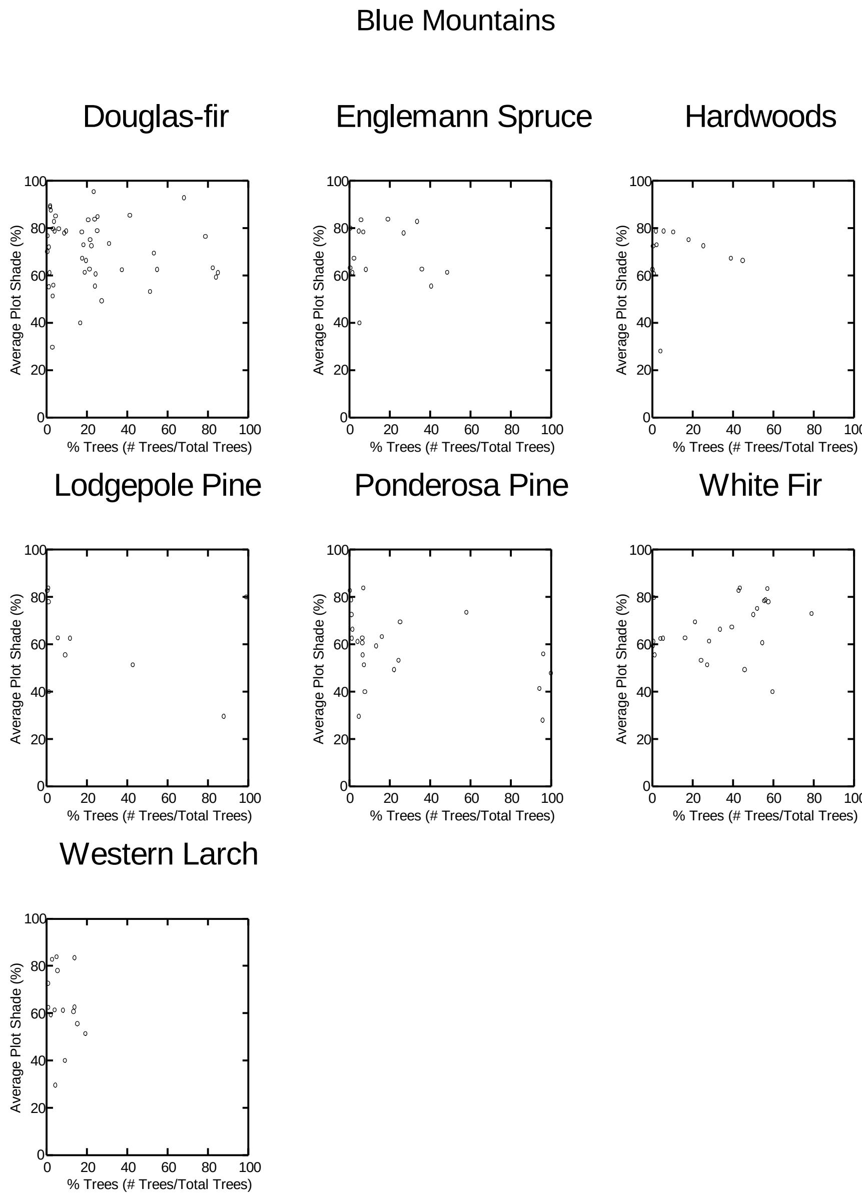


Figure D-1. Percent shade by plot species composition in the Blue Mountains.

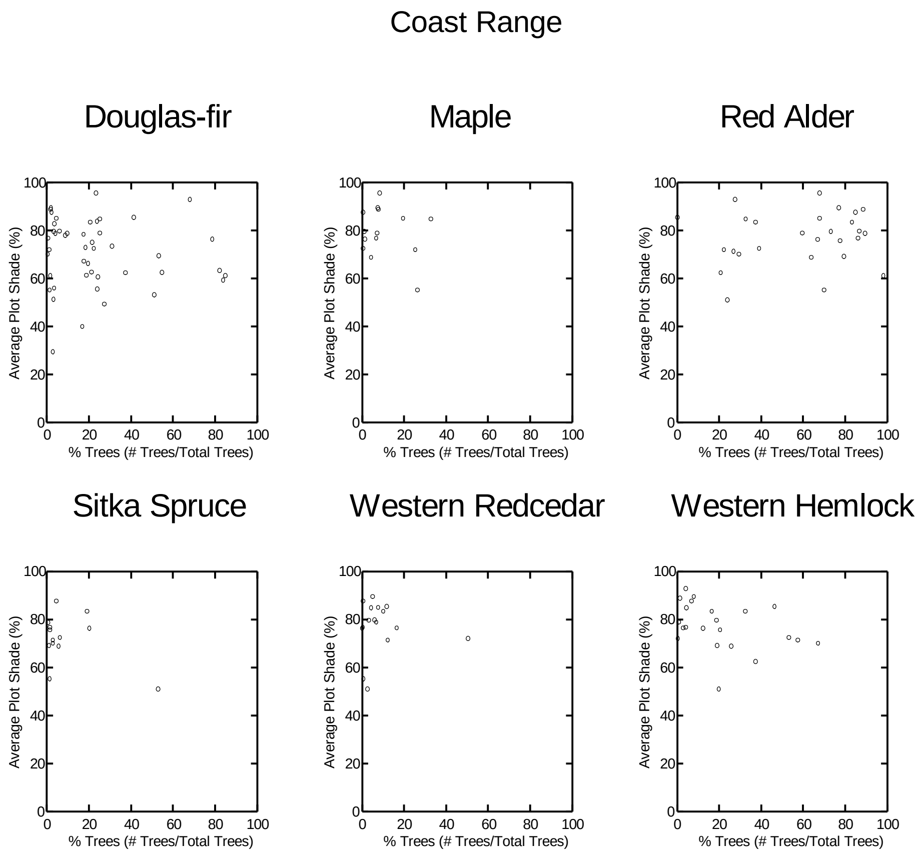


Figure D-2. Percent shade by plot species composition in the Blue Mountains.

APPENDIX E: SHADE VERSUS AVERAGE STAND CHARACTERISTICS OF BOTH SIDES OF THE STREAM

WHOLE (BOTH SIDES OF THE STREAM AVERAGED TOGETHER) RIPARIAN STAND CHARACTERISTICS AND SHADE.

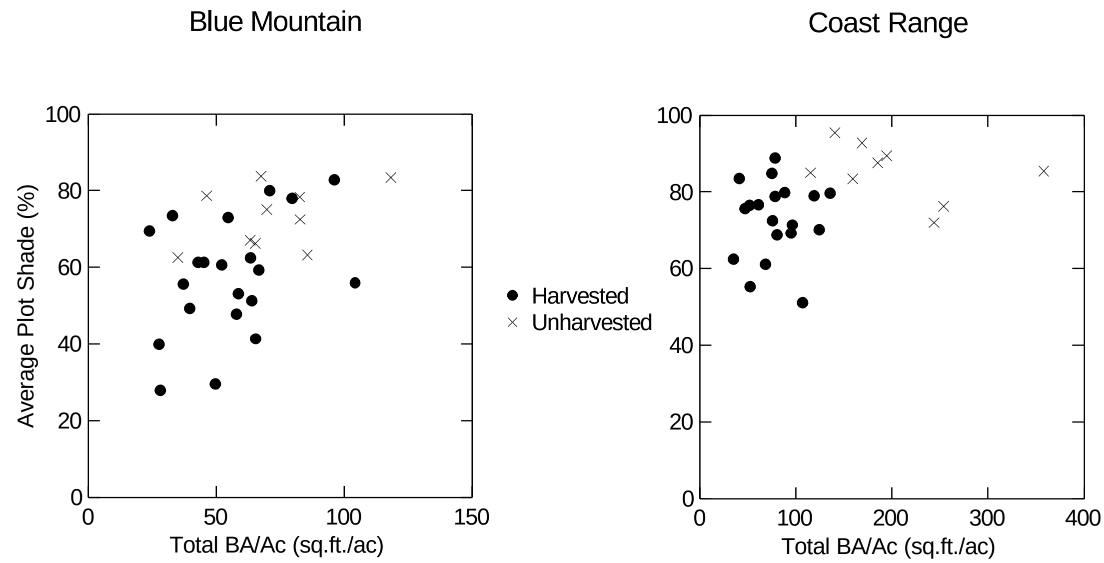


Figure E-1. Percent shade by whole-plot basal area per acre for each georegion in harvested and unharvested stands.

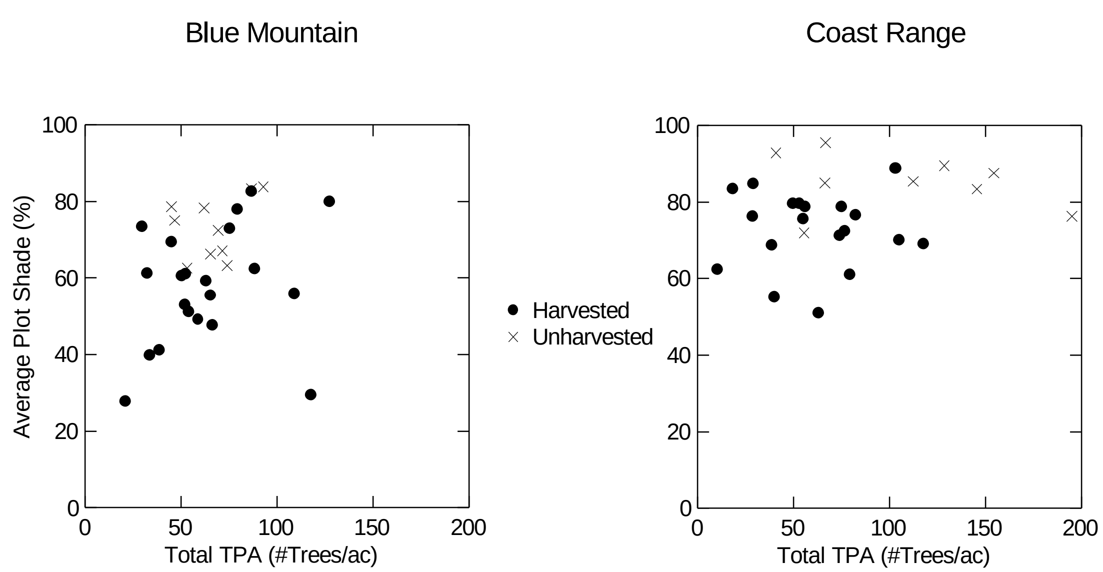


Figure E-2. Percent shade by whole-plot trees per acre for each georegion in harvested and unharvested stands.

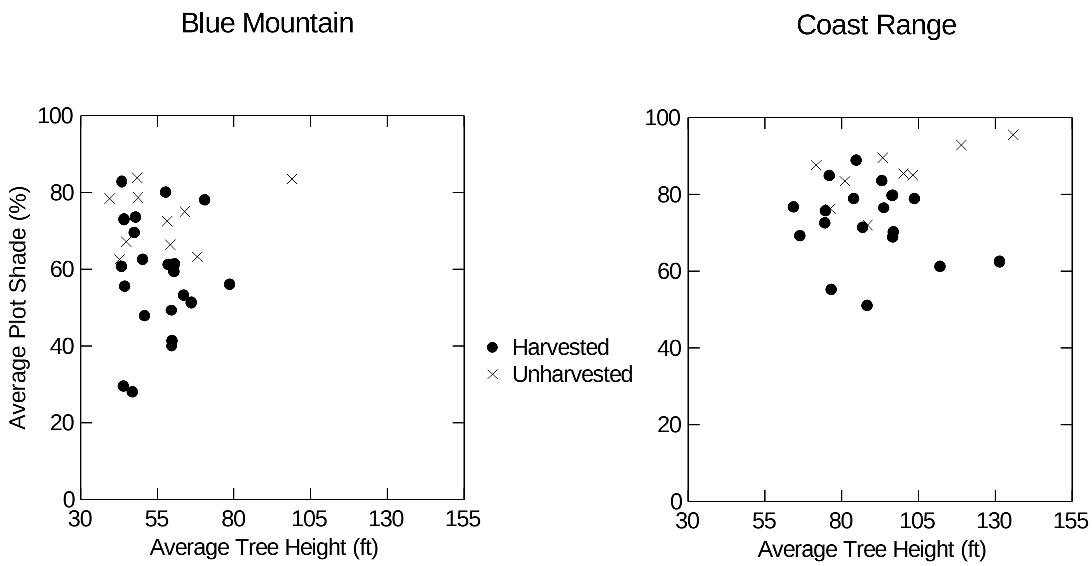


Figure E-3. Percent shade by average tree height for each georegion in harvested and unharvested stands.

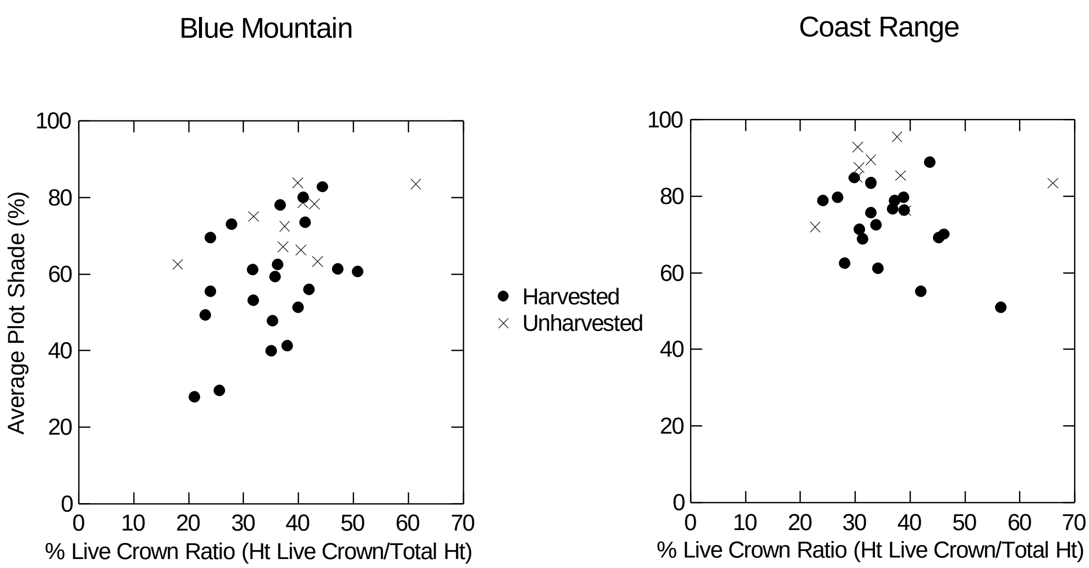


Figure E-4. Percent shade by whole-plot live crown ratio for each georegion in harvested and unharvested stands.

Cumulative Basal Area per Acre by Shade Category and Georegion

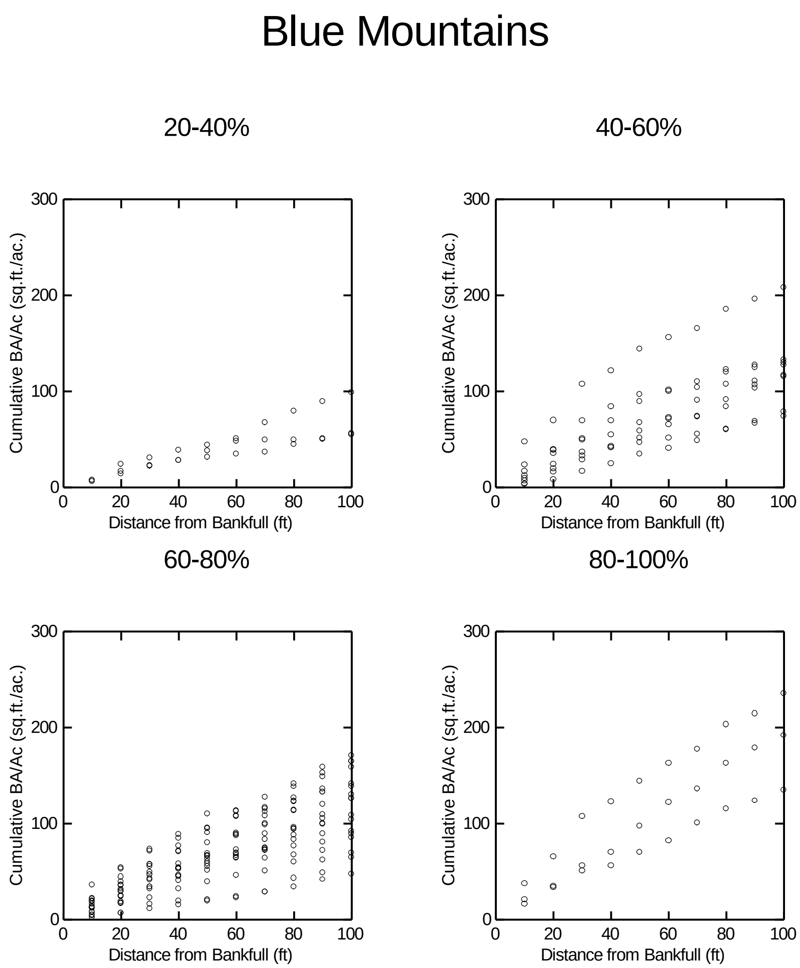


Figure E-5. Cumulative whole-plot basal area per acre versus distance from bankfull by shade category in the Blue Mountains.

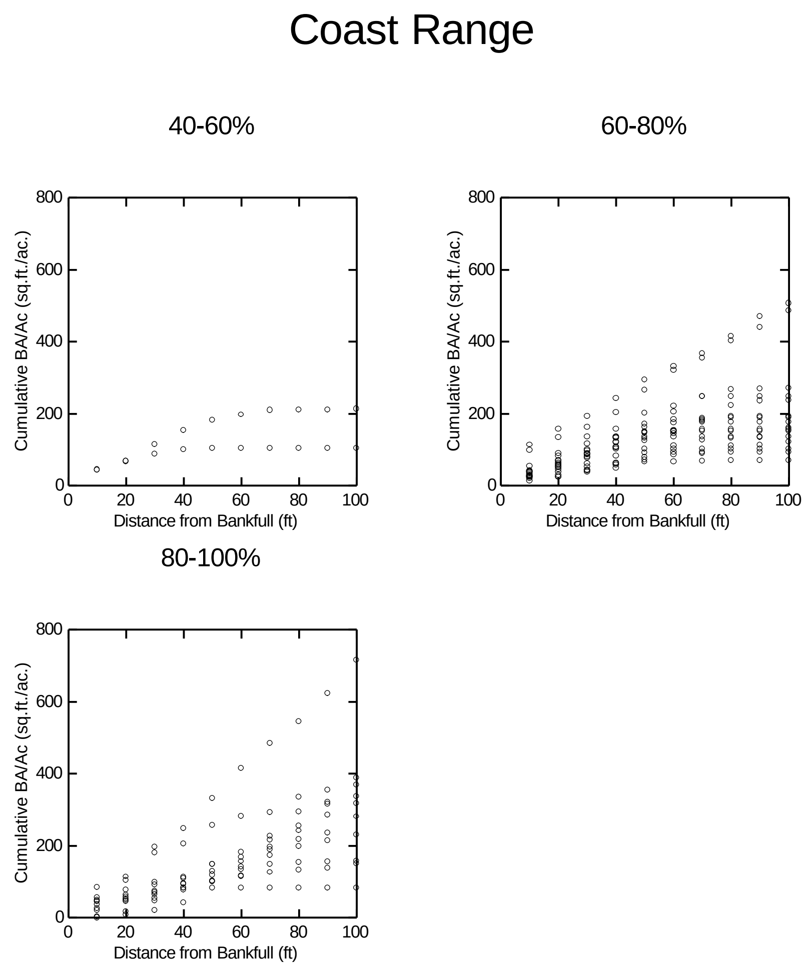


Figure E-6. Cumulative whole-plot basal area per acre versus distance from bankfull by shade category in the Coast Range